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THE ABSORPTION OF SOME GASES FOR LIGHT OF VERY SHORT WAVE-LENGTH

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The only data on the absorption of gases for light more refrangible than λ 1850 have been collected by Victor Schumann. He has investigated[1] the behavior of oxygen, hydrogen, nitrogen, carbon monoxide, carbon dioxide, and water vapor. The results are of extreme importance and interest, but their value is somewhat limited by the nature of the instrument which was used to carry on the work: for Schumann's prism spectroscope could not give information as to the wave-length of the light which it analyzed; and moreover, because of its inherent aberrations, the results which it yielded were exposed to some slight error if the work extended over a considerable spectral region.

It seemed worth while, therefore, both on practical and theoretical grounds, to go over the work with the aid of the vacuum-grating spectroscope. Accordingly, the absorption of hydrogen, oxygen, nitrogen, carbon monoxide, and carbon dioxide has been investigated and to these gases treated by Schumann argon and helium have been added. The results are in good general agreement with those obtained by the earlier investigator with the exception of the facts which relate to the absorption of oxygen. From Schumann's work it might be supposed that this gas completely absorbed all

[1] *Smithsonian Contributions*, No. 1413.

wave-lengths shorter than a certain value; from the present investigation, however, it will appear that the absorption is in the form of a band.

In addition to this feature oxygen presents an interesting contrast to the optical behavior of the other elementary gases investigated. For while hydrogen, argon, and helium seem all perfectly transparent in columns about a centimeter in length at atmospheric pressure, and while the absorption of nitrogen is very small, the absorption of oxygen is extremely strong. This fact taken in conjunction with considerations based on known photo-chemical phenomena suggested to the writer that the mechanism of absorption in the case of oxygen might be different from that which conditions the optical behavior of the other gases just mentioned. Some experiments have accordingly been made on the ozonizing effect of light, with the idea of extending the researches of Lenard and others into the region of extremely short wave-lengths. The outcome of these experiments is quite striking, for it appears that the ozonizing power of light increases very rapidly with decrease in wave-length beyond the point λ 1850. These results are of all the more interest since they appear to have some theoretical bearing on the behavior of the oxygen absorption band under change of pressure; the effect is very characteristic and consists in an unsymmetrical extension of the band. Now Larmor has predicted that, under certain conditions, such an unsymmetrical extension of the band will take place; the author's study of the formation of ozone seems to indicate that in the case of oxygen these conditions exist.

The band under consideration offers excellent opportunity for a test of Beer's Law. Work on this subject has already been undertaken and it is hoped that the results will form the substance of a future paper. The present measurements, however, are all concerned with absorption for a constant thickness.

As the absorbing action of oxygen offers a contrast to the behavior of the other simple gases investigated, so the behavior of its compounds—carbon monoxide and carbon dioxide—might be expected to show peculiarities. This expectation is borne out by experiment. The absorption spectrum of carbon monoxide consists of eight narrow bands, of a very striking appearance.

The practical result of the research relates to the nature of the absorption of air itself. The action seems to be conditioned entirely by the absorption of the oxygen with the slight absorption of nitrogen in the region near λ 1300 added to it. The effect of such quantities of ozone and water-vapor as exist in the atmosphere under normal conditions seem to be negligible.

It is greatly to be deplored that the opacity of fluorite limits the range of these experiments at a point in the spectrum considerably short of the present known limit, and in a region of special interest. Up to the present time, however, no substance more transparent than fluorite has been discovered.[1]

The following pages will contain a detailed account of the investigation.

APPARATUS

The apparatus is the same as that used in the measurement of the hydrogen spectrum,[2] except for the addition of the absorption chamber and for an improvement in the manner of attaching the discharge tube which served as a source of light.

The absorption chamber consisted of a vessel of glass 0.914 cm thick and 2 cm in diameter; it was provided with two ground flanges on which the windows of clear white fluorite were fastened with Khotinski cement. This chamber was attached to the inside of the face-plate of the vacuum receiver by means of the same cement. The outlet pipe of the chamber passed through a hole in the face-plate air-tight, and was connected to a mercury pump, a McLeod gauge, and the source of gas under investigation. Thus the arrangement was such that the light from the source passed through the absorption chamber before falling on the slit of the spectroscope.

The improvement in attaching the discharge tube was brought about by the employment of a brass collar *A* fitted with a screw thread. Into this collar the discharge tube was cast with Khotinski cement. The collar was then screwed into a cup *B*, which in turn screwed into a face-plate *C*.

The collar permitted the discharge tube to be removed without disturbing the rest of the apparatus. The cup allowed the use of an

[1] *Astrophysical Journal*, 25, 45, 1907.

[2] *Ibid.*, 23, 181, 1906.

extra fluorite window cemented in it, when so desired. In the absorption work no such extra window was used, since the chamber *D* fitted air-tight on the face-plate and served to separate the vacuum receiver from the discharge tube. This latter piece of apparatus was always separately exhausted. The alignment of the tube, which proved troublesome in the earlier investigation, was facilitated by boring the hole in the face-plate into which the cup screwed, at the proper angle. The final adjustment was made when the tube was cemented into the collar. Fig. 1 shows the detail of the arrangement. The relation of the discharge tube to the rest of the apparatus is shown in Figs. 5 and 7 of a former article.[1]

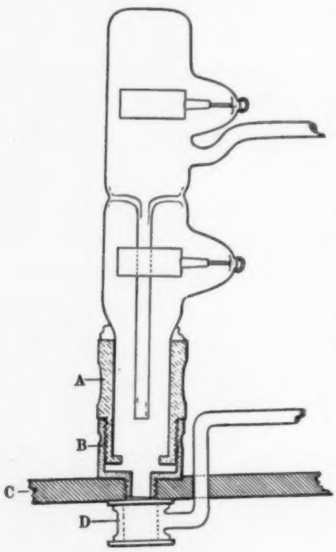


FIG. 1

It is well to note that there are three separate pumping systems in use with the apparatus, one for the vacuum receiver, one for the absorption chamber, and one for the discharge tube.

For the best results in absorption experiments a source should be used possessing a continuous spectrum, throughout which energy is equally distributed. In the region of very short wave-lengths such a source is not available. The nearest approximation to the desired condition is obtained by employing a discharge-tube filled with hydrogen containing a trace of carbon monoxide. This gas mixture gives a spectrum rich in lines and of fairly uniform intensity extending from λ 1850 to λ 1250. In practice, the discharge tube was washed with hydrogen until the visible spectrum showed that the gas was of the requisite constitution, the tube was then shut off from the pump, and the discharge was run through it for a sufficient length of time to insure its constancy during the experiment which was to follow.

The electrical excitation was furnished by the commercial trans-

[1] *Astrophysical Journal*, **23**, 181, 1906.

former described in an earlier paper. No capacity beyond that furnished by the connecting wires was introduced. In measuring the current through the tube the author has had the advantage of Professor G. W. Pierce's apparatus.[1] This current, which was of course kept as nearly constant as possible throughout the experiment, proved to have a value of about ten milliamperes. The pressure in the tube was usually about one mm. The time of exposure, which was constant for any set of measurements, was usually five minutes. The slit of the spectroscope was rather wide, namely, about 0.09 mm.

It is to be noted that the light suffers absorption, not only in the chamber itself, but in the body of the spectroscope, since it must pass over a distance of about two meters in going from the slit to the photographic plate. For good results, therefore, it is necessary that the vacuum receiver should be very free from leaks and should be carefully washed with hydrogen before the experiment begins. Under these conditions, with a gas such as oxygen in the absorption chamber, the absorption in the spectroscope itself, which contains only hydrogen, can be neglected. But with more transparent gases absorption in the spectroscope must not be lost sight of if plates obtained under varying conditions of leak are to be compared.

The manner of making the experiment was usually as follows. The absorption chamber was exhausted to a pressure of 0.02 mm or less and an exposure made. The spectrum thus recorded showed only the absorption due to the gas in the body of the spectroscope. The gas under examination was then let into the absorption chamber until the pressure, as read by the gauge, reached the desired value. A photograph of the spectrum was then taken. The pressure was again changed and another spectrum obtained; and this process was repeated until a number of spectra were recorded sufficient to cover the photographic plate, each spectrum corresponding to a different pressure in the absorption chamber. The manner in which a number of exposures can be made on one photographic plate without opening the vacuum receiver is described in a former article.

It is important to remember that, if the absorption of a gas under different pressures is to be accurately observed, it is absolutely necessary that the required spectra should be recorded on one and the

[1] *Physical Review,* **25**, 31, 1907.

same plate, for with the photographic emulsion which must be used in this spectral region[1] there is sometimes considerable variation in sensitiveness, even among plates which have been made at the same time. During any one experiment great care was taken to keep the conditions in the vacuum receiver and in the discharge tube constant. To this end after the receiver had been sufficiently washed with hydrogen the pump was kept continually in action to counteract the effect of any small leak; and the appearance of the discharge tube was constantly watched with a direct-vision spectroscope.

The pressure in the spectroscope when the experiment was in progress was of the order of 0.1 mm, and the maximum leak under which satisfactory work could be done was about 0.04 mm per hour. These conditions are much more difficult to obtain than those which suffice when a single emission spectrum is under investigation, for in the latter case, as the experiment is quickly finished, continual washings of hydrogen may be made to neutralize the effect of a very much larger leak than that mentioned above.

HYDROGEN

The absorption of this substance is stated by Schumann to be extremely small, but owing to the difficulty of producing a thick layer of the pure gas he obtained some contradictory results when working with long gas-paths.[2]

The author's data on the subject are in good agreement with these facts. The gas was prepared electrolytically from a solution of barium hydrate and dried over phosporous pentoxide. When used in the absorption chamber 0.91 cm long at a pressure of one atmosphere, it exercised no observable absorption.

An attempt was made to study its behavior in long columns by introducing it into the spectroscope itself; in this case the path was about 200 cm. Here the gas was prepared from zinc of great purity and hydrochloric acid, and was as before carefully dried by phosphorous pentoxide. Spectra taken through this gas at pressures of one to five cm show an absorption band near λ 1700, which, as it decreases with successive changes in the gas filling, evidently is due to

[1] V. Schumann, *Annalen der Physik*, 5, 349, 1901.

[2] *Smithsonian Contributions*, No. 1413, p. 18.

some impurity.[1] This contamination of the gas is probably due to the brass of which the spectroscope is made, since all connecting tubes are of glass. The weak spot in the spectrum between λ 1300 and λ 1330[2] is observed with the lowest pressures in the receiver and is always present. It is impossible to say whether this is a true absorption band for hydrogen or if it is a characteristic of the emission spectrum of the source of light itself.

At pressures near one atmosphere the absorption is considerable, the end of the spectrum being in the neighborhood of λ 1600. Here again it is impossible to say whether this action is a property of hydrogen or whether it is due to the presence of some impurity. A small trace of oxygen, for example, would account for the result. To make the experiment conclusive, it would be necessary to work with a spectroscope which could be made chemically clean. This condition would be very difficult to fulfil. The author hopes, however, to make some experiments on this subject with long columns of the gas placed in front of the slit of the instrument.

HELIUM

The author is indebted for the specimen of helium with which the work was done to the kindness of Professor E. P. Adams. In thicknesses of 0.91 cm, at atmospheric pressure, the gas shows no observable absorption in any part of the spectrum between λ 1900 and λ 1250.

ARGON

The gas was obtained from atmospheric nitrogen. I am indebted to Professor Baxter for his kindness in superintending the preparation. The gas showed a very slight trace of hydrogen in the visible spectrum. In columns of 0.91 cm it produced no observable absorption in any part of the spectrum, even when at atmospheric pressure.

NITROGEN

The gas was atmospheric nitrogen prepared in the usual way by passing air over hot copper and, like all the other gases, carefully dried.

In columns of 0.91 cm and at atmospheric pressure the gas pro-

[1] *Astrophysical Journal*, **19**, 265, 1904.

[2] *Ibid.*, **23**, 181, 1906.

duces a very slight absorption extending continuously from λ 1800 or thereabouts to λ 1250. The strength of this absorption increases slightly but regularly with decrease in wave-length, but even at the most refrangible end of the spectrum it is very small indeed.

It is interesting to note at this point that, as argon is perfectly transparent and as nitrogen is not, the matter of absorption is probably not simply connected with increasing atomic weight.

Schumann remarks: "Nitrogen proved itself very transparent even beyond $162\mu\mu$, yet it absorbed particular wave-lengths very energetically."[1] The author has been unable to observe this absorption of particular wave-lengths in the region between λ 1900 and λ 1250.

Experiments on this gas with greater lengths of path would be of interest.

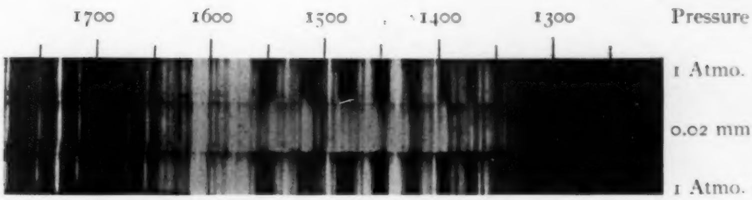
OXYGEN

The behavior of this substance affords a strong contrast to that of hydrogen, helium, argon, and nitrogen, for it absorbs light of short wave-lengths most energetically. This fact was discovered by Schumann. The present research marks a considerable advance in our knowledge of the properties of this gas, however, since from the writer's results it now appears that the absorption of oxygen is in the form of a band. This fact is entirely new.

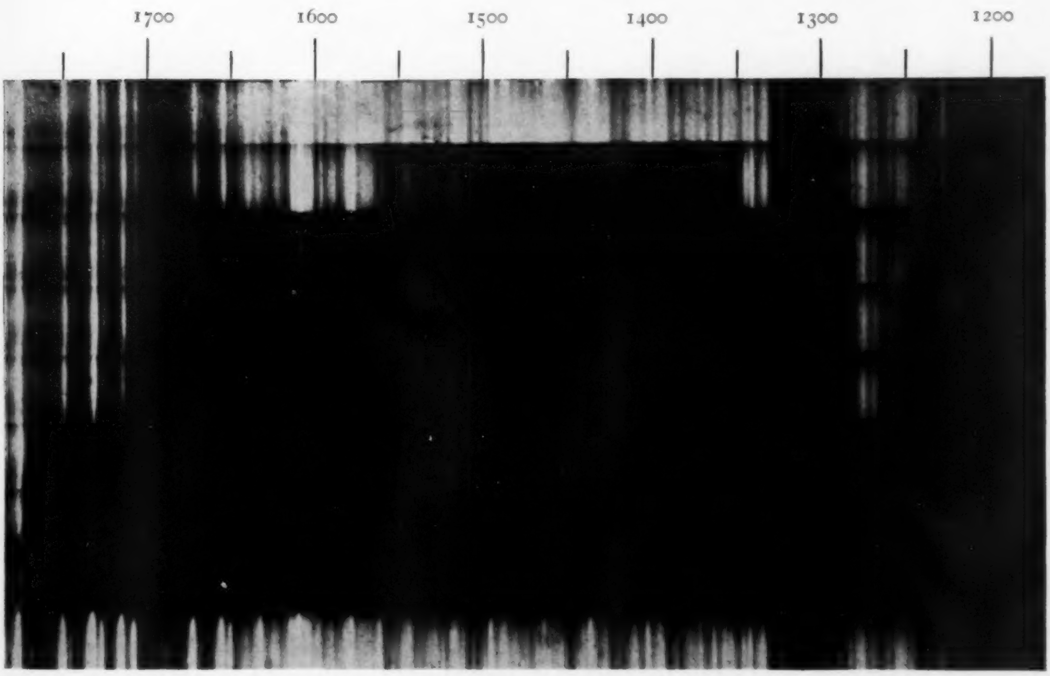
The gas was prepared electrolytically, heated to destroy ozone, and carefully dried over phosphorous pentoxide. It was then introduced into the absorption chamber and experiments on the relation of absorption to pressure were made upon it in the manner previously described. The result is shown in Plate VII. The character of the band is unmistakable. With a pressure of one atmosphere, the more refrangible limit is not visible in the reproduction, though it can be just made out in the plate itself, but as the pressure in the absorption chamber is decreased this limit comes into view. Most unfortunately a careful study of the more refrangible region is much interfered with by the absorption of the fluorite windows, which first begins to be noticeable near λ 1300. There does seem to be, however, some indication that another absorption band exists, lying in the region

[1] *Smithsonian Contributions*, No. 1413, p. 15.

PLATE VII



THE ABSORPTION OF CARBON MONOXIDE



THE ABSORPTION BAND IN OXYGEN

Beginning at second strip from top, the pressures are 0.02, 0.05, 0.07, 0.10, 0.25, 0.5, 1.0 atmospheres

shut out by the opacity of the fluorite. Nothing definite can be said on the subject and attention will, therefore, be directed chiefly to the phenomena as shown in the strong band.

The mere existence of this band is an important fact, but it is not the only result which the experiment yields. A glance at the plate is enough to show that the width of the band changes with pressure in a characteristic manner. For as the pressure increases the absorp-

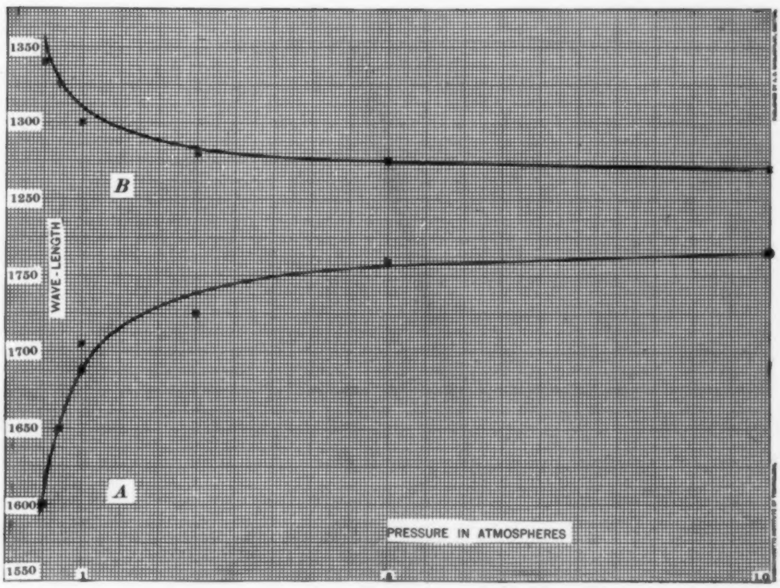


FIG. 2

tion spreads much more rapidly toward the less refrangible side than in the other direction. This action is shown graphically in Fig. 2, where the last visible wave-length is plotted against the corresponding pressure. *A* is for the less refrangible end of the band, *B* for the more refrangible limit. When it is considered that the emission spectrum is not continuous and not perfectly uniform, it is surprising how closely the points lie on the curves. It is not difficult to find empirical equations to fit the curve. For *A*, the equation takes the form

$$(\lambda_0-\lambda)p=c,$$

where λ_0 and c are constants having the values 1773 and 8.6 respectively; and B can be expressed by the relation

$$(\lambda - \lambda_0')p = D,$$

where λ_0' and D have the values 1266 and 4.5. In order to show how close the fit is, the observed points are marked with crosses and the curve is drawn through the calculated values. The agreement is fairly good, but too much weight must not be put upon it; for though the relation between the pressure and the minimum energy at the given point in the spectrum necessary to affect the photographic plate affords most alluring material for theoretical speculation, the uncertainties of the experiment make any general conclusions founded on numerical data of rather dubious value. The unequal and unknown distribution of energy in the spectrum, the possible change of sensitiveness of the photographic plate with change in wave-length, and the absorption by the fluorite windows introduce such complications into the case that any very exact relation such as that shown by the curves would seem to rest on some happy accident rather than on any fundamental principle.

Though exact numerical results cannot be expected to follow from the experiment under consideration, yet some interesting general conclusions may be deduced from the data at hand.

Unsymmetrical bands in the case of gaseous absorption are by no means unknown. Such a band exists in chlorine, as has been shown by Miss Laird,[1] and more recently Wood[2] has investigated absorption of this kind in mercury vapor. Bands of this type are of special interest.

Planck, in his work on the optical properties of gases, predicts for cases of very strong absorption the existence of bands which with change in pressure widen more rapidly on their less refrangible side than at their more refrangible limit; in addition his theory calls for an actual shift of the maximum of absorption with pressure change. Unfortunately, as Kayser has pointed out, it is almost impossible to tell by any method whether the movements of the edges of the band are real or apparent.

[1] *Astrophysical Journal*, **14**, 114, 1901.

[2] *Ibid.*, **26**, 41, 1907.

The theory of Larmor,[1] which has some application to Wood's observations of mercury, seems to have a more direct physical meaning in the present case, though we are still in the presence of the difficulties to which Kayser has called attention. Professor Larmor ascribes the unsymmetrical nature of the band in mercury to the formation of loose aggregates of molecules. He says: "The molecules in such loose aggregates would, owing to their (slight) mutual influence, vibrate in longer periods, and give rise to the displaced part of the band." Thus if the hypothesis is to have an application to the case of oxygen it will be necessary to show that the formation of such aggregates is not impossible in this gas.

With this idea in mind, it is at once remembered that oxygen stands out among the elementary gases investigated because of its extremely strong absorption. It is not unnatural to inquire, then, if the mechanism of absorption in oxygen is the same as in other gases. Granted for the moment that in hydrogen, argon, and helium such energy as is absorbed is dissipated in some kind of friction operating on the vibrating system, or, according to Planck, in radiation given out again by the system, can we conceive of still other agents which will transform energy in the case of oxygen and by which its extremely high absorption can be explained? Long ago Helmholtz[2] pointed out that such agents probably exist. "Die starke Absorption ist also von starkem Mitschwingen der Molekeln begleitet, so dass wir dabei auch Wärmeentwickelung und unter Umständen ein Zerreissen der Ionenverbindungen erwarten können, namentlich wenn noch eine elektrostatische Ladung der Substanz hinzukommt. So sind wohl die Beobachtungen von Hertz zu erklären über die Entweichung der Elektricität unter den Einfluss der ultravioletten Strahlen."

The action observed by Hertz is now believed to be due to the action of light upon a solid rather than upon a gas; the passage is quoted, however, as it suggests directly the nature of the agents by whose action the absorption of oxygen is distinguished from that of other simple gases. These agents are ionization, and the formation of ozone or hydrogen peroxide.

On the subject of the ionization produced by ultra-violet light,

[1] *Astrophysical Journal*, **26**, 120, 1907.

[2] *Vorlesungen*, Band V, 342.

we have the work of Lenard.[1] Lately an observation has been carried on in this laboratory which corroborates the results obtained by the earlier observers and which, it is hoped, will throw light on the question of the relation of ionization to wave-length. The work is not yet finished, but it may be stated with certainty that volume ionization is produced to a considerable extent by light of such wave-lengths as we are concerned with in the present investigation.

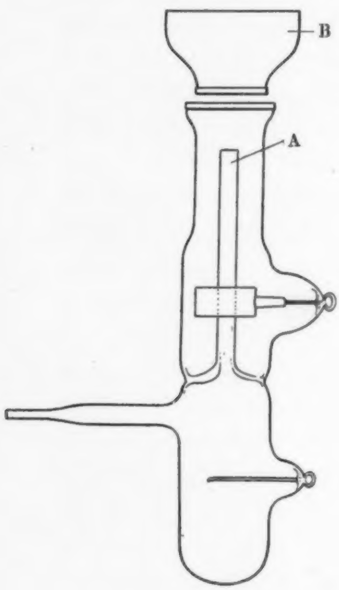


FIG. 3

On the question of chemical action produced by ultra-violet light, there is considerable data at hand. Most of the investigators, however, including Lenard, have limited themselves to light less refrangible than that of wave-length λ 1800, and in the case of those who have probably used a shorter wave-length there was no means of determining the exact position in the spectrum of the vibrations which yielded the results. The writer has, therefore, undertaken some simple experiments on the subject, which, as they have to do with the question in hand, will be described here.

A discharge tube of the internal capillary type, Fig. 3, was filled with hydrogen to about one mm pressure and closed by a fluorite window. The tube was excited by the transformer previously mentioned; there was no capacity in circuit. The current was of the order of ten milliamperes. Under these conditions the gas showed the many-line spectrum of hydrogen. The following experiments were then tried:

1. Half of the fluorite window was protected by a piece of microscope cover glass and over it was laid a bit of paper moistened with starch paste containing potassium iodide; in fifteen seconds the paper turned strongly blue where it was not protected by the glass, the protected portion remaining perfectly unaltered.

[1] *Annalen der Physik*, 1, 486, 1900.

2. A piece of quartz two mm thick was next placed on the fluorite window so as completely to cover it; the test paper was placed on the quartz. In fifteen seconds there was a noticeable discoloration of the paper, but the effect was not nearly so well marked as in case 1.

3. A shallow vessel *B* with a fluorite bottom was next placed directly upon the discharge tube so that the two fluorite plates were in contact. The test papers placed within this vessel upon the fluorite bottom showed in fifteen seconds a discoloration only slightly less than that observed in case 1.

4. The vessel *B* was now raised one-half mm above the window of the tube; thus the light was forced to penetrate a column of air one-half mm thick in addition to the fluorite plates; the discoloration of the paper in fifteen seconds was now very slight.

5. If the vessel was removed to a distance of one mm, no discoloration could be observed. It is evident that the agency which produces the discoloration is weakened by quartz and is, so far as these experiments show, entirely cut off by one mm of air. There can be but little doubt that the agency is light of a shorter wave-length than λ 1850.

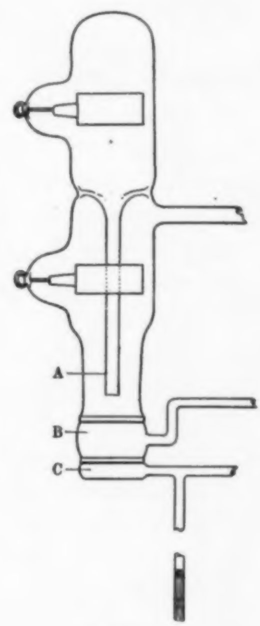


FIG. 4

A more elaborate experiment was next undertaken. A discharge tube had cemented upon its fluorite window a chamber *B*, 0.7 cm thick; this chamber in turn was closed by a fluorite window which carried a second shallow vessel *C*, 0.1 cm thick. This last vessel was connected to a manometer column which dipped in strong sulphuric acid. The function of the chamber *B* was to serve as a screen of variable transparency, and to this end it was connected to a mercury pump and McLeod gauge. The discharge tube was filled with hydrogen at about one mm pressure. The vessel *C* was filled with oxygen at atmospheric pressure. No change in the manometer column was observed when the discharge tube was excited. It was only when the pressure in *B* had been reduced to about one cm that the acid in

the manometer column began to rise, but this rise continued to increase as the pressure in *B* was reduced step by step. Care was taken to correct as far as possible from heat effects.

The results with this more complex apparatus are only of a preliminary character. They serve to corroborate the results of the simpler experiment. There seems to be no doubt that light of wave-lengths shorter than λ 1850 acts to produce chemical action energetically, and that this action increases considerably in strength with decrease in wave-length in the region more refrangible than λ 1850.

That ultra-violet light produces ozone is a very well-known fact, but the writer believes that the action of such a feeble source of light as a hydrogen tube in producing change in the gas around it has not before been observed. The connection between the magnitude of this change and the wave-length of light has probably also not been recorded, at least for the spectral region under discussion. It must be remarked, however, that the starch-paper test cannot distinguish any more than the manometer between the production of ozone and hydrogen peroxide. The gas formed may be either the one or the other.

The whole question of the relation of wave-length to the velocity of chemical reactions which are affected by light is one of extreme interest. A research on this subject is now in progress in this laboratory.

We may now return to Larmor's theory of the unsymmetrical broadening of the oxygen band. It is evident that the required molecular aggregates are furnished either by ionization or by the products of chemical action, or more probably by both agencies working together. If, therefore, the apparent shift of the limit of the band is in fact a real shift, the theory of Larmor has received corroboration at the hands of the oxygen band.

An investigation of the behavior of the band in chlorine or in mercury vapor under pressure change might yield interesting results; the writer hopes to turn his attention to the matter at some later time.

In conclusion it is important to inquire what the optical properties of ozone are in the region under examination, for it seems very probable that this substance is formed in oxygen during the process of absorption. Schumann states: "The presence of a moderate

amount of ozone does not alter the absorption at all." The writer's experiments bear out this conclusion. Ozone was made by the action of the silent discharge; it was then run over phosphorous pentoxide and introduced into the absorption chamber. No difference could be noted between the absorption of pure oxygen and that produced by oxygen containing ozone.

The absorption in oxygen therefore, though it is closely connected with the production of ozone, does not seem to be affected by the presence of the gas when produced from another source.

So far all the results which have come under discussion were obtained by varying the pressure with a fixed thickness of gas. The oxygen band, however, offers a good opportunity for a test of Beer's Law, and the writer hopes to collect data similar to those here presented, but for various path lengths, at some future time. The work, however, is tedious and the inherent difficulties of such experiments will probably cause some delay.

Schumann has observed fourteen groups of absorption lines near λ 1850 which he attributes to the action of oxygen. He says: "These groups which are of bandlike form constantly approach nearer one another with their deviation and are shaded off toward the red. Complete absorption is to be found with the most refrangible of them."

The writer has never been able to get satisfactory photographic records of this phenomenon, perhaps because of the difficulty he has experienced in obtaining a continuous spectrum of any strength in the neighborhood of λ 1850 and because the slit of his spectroscope falls short in perfection of the extremely beautiful instrument used by Schumann.

It must be noted that these groups exist at the less refrangible end of the great absorption band. Judged in relation to it, they are probably of a feeble character.

CARBON DIOXIDE

The gas was prepared by heating sodium bicarbonate, and was dried over phosphorous pentoxide. The absorbing action is similar to that of oxygen, but much less energetic. Thus at one atmosphere pressure the last visible wave-length with oxygen is λ 1760, while with carbon dioxide it lies near λ 1600. The relation of least visible

wave-length to pressure resembles that found in oxygen, but the curve which shows the results is far less smooth than in the case of the simpler gas. There is considerable probability that this effect is produced by maxima and minima which occur throughout the band; in fact, some of the minima are clearly evident when the absorption of the gas is observed at low pressures. They occur in the region between λ 1600 and λ 1300. Schumann has observed similar narrow bands at the less refrangible end of the region.

Unlike oxygen, the more refrangible limit of the band has not been discovered, perhaps because it lies in the region shut off by the opacity of fluorite.

CARBON MONOXIDE

The gas was prepared from oxalic and sulphuric acids and dried as usual.

The absorption is very characteristic and quite unlike that of oxygen, as may be seen from Plate VII. There seems to be very little action from λ 1850 to λ 1600, but from λ 1650 to λ 1250 eight separate bands exist. The maxima occur near λ 1548, 1512, 1482, 1450, 1423, 1395, 1370, 1345. For any given pressure they decrease in width with decrease in wave-length. As the pressure is reduced, each band contracts, but even at a value of 0.1 of an atmosphere, all the bands are still distinguishable. They do not correspond to any lines or groups of lines in the emission spectrum of the gas. At least two of the bands seem to coincide with those observed in carbon dioxide. The limit of the spectrum as shown in the illustration is not due to absorption but to the character of the source of light.

Schumann speaks of carbon monoxide as producing "a series of rhythmical inverted groups of lines." As he confined his attention almost entirely to the part of the spectrum on the less refrangible side of λ 1600 it is probable that this group of lines does not coincide with the bands which are illustrated in the accompanying plate and which lie in the region below this limit. As in the case of oxygen the writer has been unable to obtain any satisfactory data as to the existence of the less refrangible minima.

The absorption of carbon monoxide, so different from that of any of the other gases so far investigated, deserves further study. Like all the experiments described in this paper, the results were obtained

for a single gas thickness of 0.91 cm. Longer gas paths should yield interesting data.

AIR

The absorption of the air is one of the most important factors in all practical problems relating to the region of short wave-lengths, and direct experiments were, therefore, made on the subject even before the work on the elementary gases was begun; exactly the same method being followed in making observations on the effect of change of pressure as was employed later with other gases.

It appears that the absorption of carefully dried air can be described as due to the absorptions of the oxygen and nitrogen which it contains. As might be expected, it is more transparent than oxygen, for, while with oxygen at atmospheric pressure and a path of 0.91 cm the last visible wave-length is near λ 1760, for air under similar circumstances it is near λ 1710. Moreover, in air as in oxygen the absorption is in the form of a band. There is one difference to be observed, however, between the action of the gas mixture and that of the element, for with air the more refrangible end of the band is rather indistinct, while with oxygen at a corresponding pressure it is extremely sharp. This effect is probably due to the presence of nitrogen whose absorption, though very slight, is yet enough in the region of shortest wave-lengths to account for the result. It seems improbable that such traces of ozone, carbon monoxide, and carbon dioxide as are ordinarily to be found in the atmosphere can have any marked effect upon its absorption for that part of the spectrum which has been considered in this paper. Moreover, from experiments on dry and moist air, the effect of such quantities of water vapor as occur in the air of a laboratory seem to be negligible, at least within the limits of these experiments.

It must be remembered, however, that in treating the absorption of the atmosphere for light less refrangible than λ 1900, these statements may not be true. Ozone, for example, is known to exercise strong absorption in the region between λ 3000 and λ 2000; in fact, the limit of the solar spectrum has been ascribed by Hartley and others to its presence in the atmosphere. It seems not improbable, therefore, that the agents which determine the opacity of the air for light of greater wave-length than λ 2000 may be somewhat different

in nature from those whose action produces the absorption of light of wave-lengths more refrangible than this value.

Finally, it is of considerable interest to inquire what inference may be drawn from the data at hand as to the transparency of the air for light of even shorter wave-length than that which is recorded on these plates. For it is obvious that if it could be shown that the air is transparent to ether vibrations of very high frequency the result would be of considerable importance.

Unfortunately, nothing very definite can be said on the subject. The fact that the ultra-violet limit of the absorption band in oxygen appears to spread in both directions with decrease in pressure points to the existence of a second region of absorption beyond the point at which fluorite becomes opaque. Moreover, as far as the data now at hand are concerned the absorption of nitrogen seems to increase rather regularly with decrease in wave-length. These facts taken together would indicate that no great improvement in the transparency of the air for light more refrangible than λ 1250 is to be expected. On the other hand, since the limits of one oxygen band have been discovered, it seems not improbable that if a second band exists, it too will have its end; moreover, it is perhaps legitimate to surmise that the absorption of nitrogen is in the form of a band and that for very short wave-lengths this gas also may regain its transparency.

In short, though it seems improbable that the air is transparent for light of the very shortest wave-length, yet the results of this research indicate that such a state of things is not impossible.

CONCLUSIONS

1. The absorption of hydrogen, argon, helium, nitrogen, oxygen, carbon monoxide, and carbon dioxide has been investigated for a single thickness, but with varying pressure, between λ 1850 and λ 1250.

2. Hydrogen, argon, and helium in thicknesses of 0.91 cm and at atmospheric pressure produce no observable absorption in this region.

3. The absorption of nitrogen, though slight, is perfectly perceptible even for a thickness of 0.91 cm. The absorption appears to increase with decrease in wave-length.

4. The absorption of oxygen takes the form of a band extending,

if the thickness is 0.91 cm and the pressure is atmospheric, from near λ 1760 to near λ 1270. The behavior of this band with change in pressure has been studied. The mechanism of the absorption of oxygen as distinguished from that in other gases has been discussed and some new experiments on the effect of light of very short wave-length in producing chemical change have been tried. The results have been found to bear upon a theory of the unsymmetrical shift of the limits of absorption.

5. The absorption of carbon monoxide has been found to be unlike that produced by oxygen, in that it is characterized not by one broad band, but by eight narrow bands in the region between λ 1600 and λ 1250.

6. The absorption of carbon dioxide is characterized by the presence of a broad band slightly resembling that due to oxygen, but complicated by the presence of maxima and minima within its limits.

7. The absorption of the air for the region between λ 1850 and λ 1250 appears to be due to the combined actions of the oxygen and nitrogen which it contains. Under the conditions of this research, in thickness of 0.91 cm and at the pressure of one atmosphere the last visible wave-length lies in the neighborhood of λ 1710. As in the case of oxygen the absorption is in the form of a band.

Jefferson Physical Laboratory
Harvard University
December 28, 1907

THE FUNCTION OF A COLOR-FILTER AND "ISOCHROMATIC" PLATE IN ASTRONOMICAL PHOTOGRAPHY

By ROBERT JAMES WALLACE

The new era in photographic science, opened by the introduction of the (so-called) isochromatic plate and its accompanying color-filter, was pregnant with significance to astronomers in general throughout the world, for that hitherto while the application of photography to the recording of results could be attained only by the possession of an expensive correcting lens, the simple combination of a color-filter and isochromatic plate not only fulfilled all requirements, but did so more perfectly.

It requires but little consideration to arrive at the very logical conclusion that, whether an individual be equipped with but rudimentary photographic knowledge or an extended experience, successful results are more or less a matter of "accidentals." Natural causes compel that this must be so, i. e., the unsteadiness of the earth's atmosphere, and consequent "bad seeing." Every astronomer knows that during the period of an observation there are moments when the image appears to "steady down" and detail "flashes out," only to be again lost in the ensuing "boiling." In the case of a large image like the moon, these moments of steadiness can be watched for and taken advantage of when they occur; but, naturally, it is the exposure of plate after plate, or, the exposure of portion after portion of the same plate, that gives results; because it is obvious that, given even fairly good seeing, the development of a large number of exposures taken consecutively throughout the period must result in some that are much better than others, since the better ones utilize the light during a momentary steadiness. It follows, therefore, that the steadier the air the greater the percentage of good images, and the greater the number of exposures the better the chance for success.

Assuming the possession of a telescope and camera-box, together with a plentiful supply of plates and a modicum of manipulative photographic knowledge (which is not synonymous with a knowledge of photography), there are but few things less difficult than obtaining

results in so far as the operator is concerned; the only element of uncertainty introduced being the atmospheric disturbances, over which he has absolutely no shadow of control. The focus is fixed by star-trails at any time prior to the exposure, and once determined it remains constant except for temperature, which by contraction or expansion of the metal parts of the telescope, or change of figure in the objective, shifts the focal plane nearer to or farther from the objective. Several settings, however, at varying temperatures provide points upon which is erected a focal curve, the casual observation of which, before or during work, instantly indicates the exact focal setting.

It is an almost incomprehensible fact that while the principles underlying the use of color-filters and "isochromatic" plates are very thoroughly understood by all students of photography, yet in astronomical circles generally the most vague and visionary ideas are entertained, and this too, in many cases, by the very individuals who are making constant use of both. It is unfortunate that the data relative to the subject is almost wholly scattered throughout the photographic and other journals (mostly European), and so much has been written by so many people, that to attempt the compilation and necessary editing of the material would be a task truly herculean. The purpose of the present paper, therefore, is an attempt to set forth connectedly the principles governing their use.

In the adjustment of a color-filter to a visual refracting telescope the point of first consideration is the correction of the lens for color, i. e., the "color-curve." Generally speaking, the region from λ 5400–λ 5900 represents the portion most nearly flat, viz., where the rays approximately come to the same focus, while the focal points of different wave-lengths lie at a gradually increasing distance apart. As a typical example of a visually corrected Clark objective, the color curve for the 40-inch telescope is shown in Fig. 1.

If all light-rays passing through the objective were to come to a focus at the same plane, then of course the color curve would be represented as *f*, and when photography was attempted it would simply be sufficient to place in that plane a photographic plate whose selective sensitiveness it would not be necessary to consider.

Strictly speaking, there is only one point upon the curve which is

directly coincident with *f*; but generally speaking, and in practical consideration, a much greater extent is permissible, this extent being limited by the diameter of the confusion circles, which are themselves dependent upon the angle subtended by the objective.

In the case of the 40-inch telescope the angle subtended at the visual focus equals almost 3°. Considering the light-ray at λ 5650

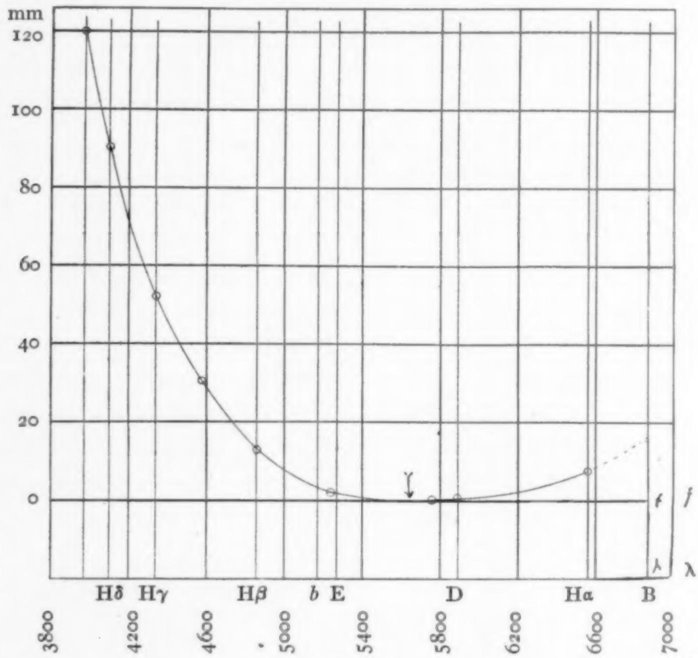


FIG. 1.

(indicated on the figure by an arrow) as forming a point source at the plane of the plate at *f*, it will be seen that the different focus points of different wave-lengths will be spread out into confusion circles of greater or less diameter as the rays cross nearer to or farther from that plane. Light, therefore, of λ 4800 and λ 6700 will be spread out from a point source into a circle whose diameter equals about 0.7 mm. As the intensity of the light is diminished in inverse proportion to the surface, it follows then that a light-intensity of unit value at its focal point must possess a weakened photo-chemical value according to the distance the plate is removed from that focal point. Hence it

cannot produce the same effect upon a photographic film unless the time of exposure be proportionately extended, such extension from investigations by Abney,[1] Schwarzschild,[2] Mees and Sheppard,[3] and others, being represented as $I \times t^p$ the value of the exponent[4] being less than unity, and varying with different plates. In all probability it also varies with the wave-length.[5]

The value or amount of this weakening of the light is, however, dependent upon another factor, and *that* a most important one, viz., the sensitiveness of the plate to the wave-length in question. The portion of the color curve which approximates a straight line lies in the very region to which the ordinary photographic film is entirely insensitive, and hence enters the isochromatic plate.

It is an interesting coincidence that it is just thirty-four years ago this month that the first publication was made in English of Dr. H. W. Vogel's discovery on photographic sensitiveness to rays of longer wave-length than the blue, by the introduction to the emulsion of sundry dyestuffs and also the first use of a color-filter. Vogel's original announcement was made just one month prior. It does at first sight appear somewhat strange that, in spite of the almost immediate and since continued activity of the plate-manufacturer, the commercial "iso" or orthochromatic plate of today is practically but a very slight advance upon the primary discovery. It is nevertheless a disagreeable fact.

The difference in selective sensitiveness between the ordinary and the isochromatic is plainly shown in Fig. 2, which illustrates graphically the sensitiveness curves of a Seed "27" and a Cramer "Instantaneous Isochromatic."

It will be noticed that the "iso" plate possesses a secondary maximum at about λ 5600, which is approximately even in intensity from λ 5300 to λ 5700, a most convenient coincidence, as this region corresponds precisely with the flat portion of the objective color curve.

1 *Proc. Roy. Soc.*, 54, 143, 1893.

2 *Astrophysical Journal*, 11, 89, 1900.

3 *Theory of the Photographic Process*, p. 214.

4 Where I = intensity, and t = time of exposure.

5 A. Becker and A. Werner, "Das photographische Reziprozitätsgesetz für Bromsilbergelatin bei Erregung mit Licht verschiedener Wellenlänge," *Zeitschrift für wissenschaftliche Photographie*, 5, 382, 1907.

It results therefore that if the isochromatic plate be placed in the plane of *j*, the secondary sensitiveness of the plate and the focus for the yellow-green rays are coincident. It is of course true that all of the wave-lengths between say λ 5200 and λ 5900 do not come to *precisely* the same focus, but they do so with practical identity.

The strong maximum at the blue end of the isochromatic plate is an unfortunate condition which up to the present has not been sus-

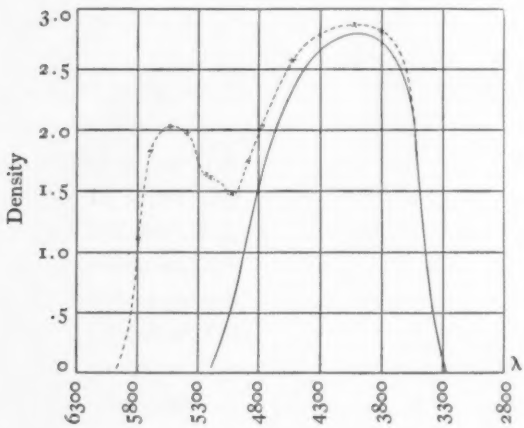


FIG. 2

ceptible of much improvement. It does not exist from lack of effort to remove it, because both the plate-manufacturer and the independent investigator have devoted much time to its subjection, but without satisfactory results; for while it has been possible to lower it by the introduction to the film of otherwise inert dyes whose absorption corresponded with the blue maximum, yet it has been at the expense of speed, which is thereby greatly lowered. The Cramer "*slow* iso" is typical of such a plate.

It might at first thought be considered possible (and several astronomers have attempted) to make use of such a stained plate in astronomical photography; but it must be remembered that, although the sensitive film may be so loaded with dye as effectually to filter out the overactive blue-violet rays from the light transmitted by it, yet on the surface of the film the particles of silver bromide are covered with a layer of dye of extreme attenuation; hence there would always

be action by the blue-violet light although in a lessened degree, which would result more or less in submergence of the sharp image under a veil of confused out-of-focus light of comparatively great actinic energy. The out-of-focus red light at the other end of the curve need not be considered, as the plate is insensitive to radiations of this wave-length, even with very prolonged exposure. The only practical method for the elimination of this out-of-focus blue-violet light is by the employment of a color-filter which will absorb it before reaching the sensitive film. It is axiomatic that pure monochromatic light acting upon the plate will produce the sharpest image.

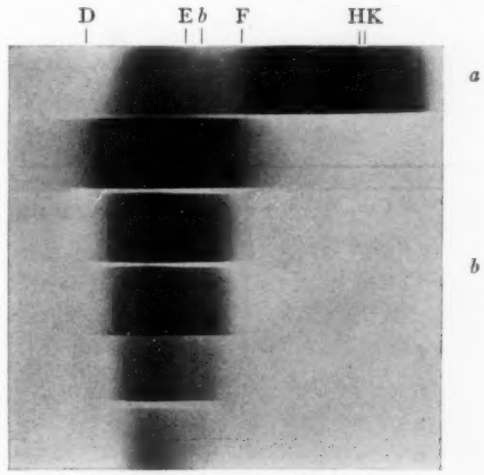


FIG. 3.—*a*. Cramer instantaneous isochromatic unscreened. *b*. Cramer isochromatic, increasing exposures through color-filter.

Not only is it impossible to construct color-filters to transmit true monochromatic light, but even if it were possible they would be valueless, because the light transmitted would be too feeble to be effective. They are constructed, therefore, to absorb all wave-lengths shorter than from about λ 4600 to λ 5400, depending upon the class of work for which they are to be used. It is necessary, generally speaking, to have a color-filter with a closer approximation to monochromatism when engaged in the photography of faint detail. This is a point well understood by all experienced photographers, and approximate monochromatic light-filters in photomicroscopy have been used a greater number of years than I would care to go on record as quoting. Such filters have also, for some time, been a regular article of commerce.

There is a great deal of uncertainty relative to the absorption of a certain color-filter, and it may as well be stated now that the photographic absorption of a color-filter, with a certain plate, depends upon the exposure which that plate receives. Increase of exposure

means increased extent of action. This is true of all filters (see Fig. 3).

The best position for the color-filter is immediately in front of the sensitive plate. In such position it is known that it displaces the image by a distance equal to $t\left(\frac{\mu-1}{\mu}\right)$ when t is the thickness, and μ refractive index; hence it is necessary, for this cause alone, to determine the position for a new filter, before exposure is made. For critical work it is necessary to determine focus separately for two color-filters, even should they possess practically the same absorption, because in manufacture, no matter what amount of care is used, small differences are unavoidable.

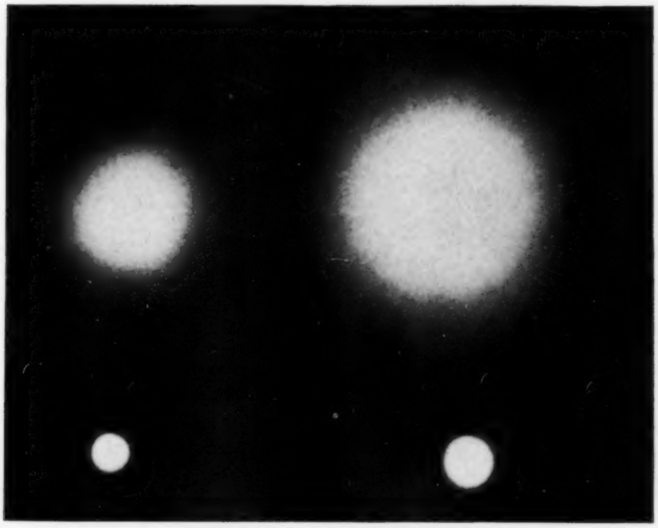
If the filters possess different absorptions, then it requires merely a primary knowledge of that and the objective's color curve, to know that the focus *must* necessarily be different.

In a paper by Dr. Schlesinger in the *Astrophysical Journal* of 1904 (**20**, 123) dealing with photographic star-images for parallax determination, an illustration is shown of a loose cluster taken with the 40-inch telescope, on an isochromatic plate, *without* the interposition of a color-screen. In this plate the enlargement is so slight—1.7 times—that the quality of the images cannot be shown. Besides, such an enlargement is in no wise comparable with that required in lunar or planetary work. A number of illustrations are therefore given (Figs. 4 and 5, Plate VIII) of series of exposures made at the 40-inch telescope upon the same star, both with and without a color-filter. The exposure times are 30 sec., 1 min. 30 sec., 4 min. 30 sec., and 13 min. 30 sec., and the enlargement is rigorously exact on each to eight diameters. The statement by Schlesinger that "careful comparison of stellar plates, taken with the screen and without, shows that there is little to choose between them, either as regards the minuteness of the images or their sharpness," cannot therefore be accepted. It should be said, however, that his comparisons were on negatives made by Ritchey with a color-filter which transmitted a considerable amount of blue light, extending almost to λ 4500; also, his statement applies particularly to faint stars, which in reality do present but little difference unless they be much enlarged.

During the period covered by the past fourteen years the writer

PLATE VIII

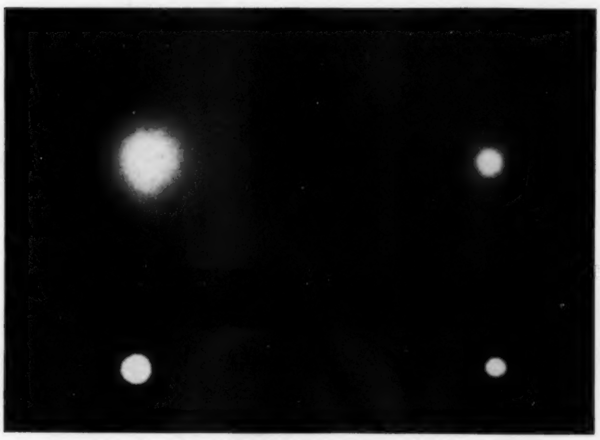
FIG 4



a

b

FIG. 5



a

b

STAR IMAGES WITH THE 40-INCH TELESCOPE

(*a*) Without color-filter, and (*b*) with color-filter
Times of exposure equal for each pair

has given considerable time to the special study of absorption filters for various conditions, and in 1903–4 devoted much labor to the critical requirements necessary in filters for astronomical photography. Use was made of the 12-inch and 40-inch telescopes and about 500 lunar and stellar negatives were made at various times throughout that period. These negatives were made under all possible (logical) variations of the color-filter, both "liquid" and "dry," and of mean transmissions of from λ 4200 through many steps to λ 5500. Some of these filters also absorbed the red end of the spectrum. This large number of negatives contained some exceedingly choice images which were selected and their filters located in the laboratory notebook. Deductions from these results showed that with a range of 100 tenth-meters within the limits of λ 4700 or λ 4800 there was no certain improvement discernible on the delineation of detail when the exposures were at the minimum allowable for normal development, although, as has been stated, *theoretically* they should increase in value as the filter approaches monochromatism.

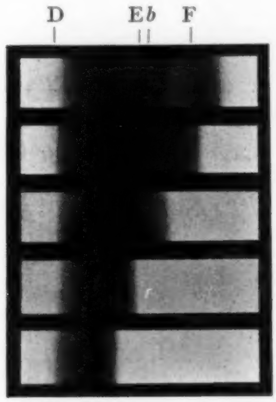


FIG. 6.—Spectral transmission of various color-filters.

Fig. 6 shows the transmission spectra of several of the color-filters used at this observatory, while Fig. 7, Plate IX, shows the difference between the images obtained with practically similar exposures by the use of filters λ 4600 and λ 4900 respectively. Between these two limits, there is noticeable a gradual increase in quality value of the images as they approach nearer to monochromatic conditions. The filter in most general use here possesses a mean absorption of λ 4900.

In the justly famed lunar negative made by Ritchey the densest color-filter used by him transmitted blue light as short as λ 4500, yet the seeing was so good, and the exposures were so successfully handled, that, from the comparatively small number made, he was enabled to select several that show a delicacy of detail which, although inferior to visual observations, has given them the premier place in photo-

graphic lunar delineation. Had the exposure been prolonged it would have been at the expense of definition—the summation effect of the action of the blue light and the atmospheric tremor.

In a recent paper by Professor Lowell there has been advanced what he terms a "new means of sharpening celestial photographic images," and the paper is illustrated by diagrams, to show the curves of color-sensitive plates, and of the Lowell objective respectively. The title is misleading, however, because fallacious, being founded upon a misconception of the theory.

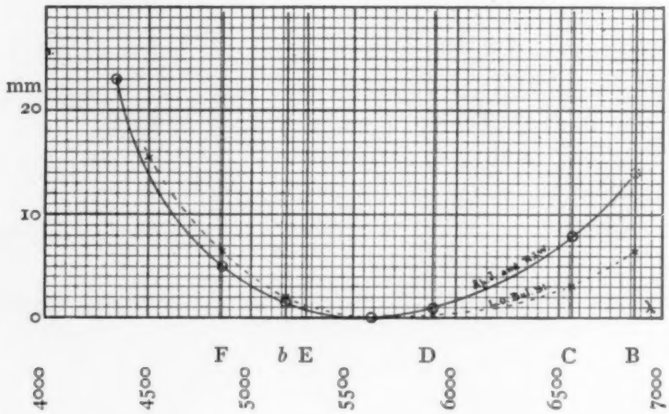


FIG. 8

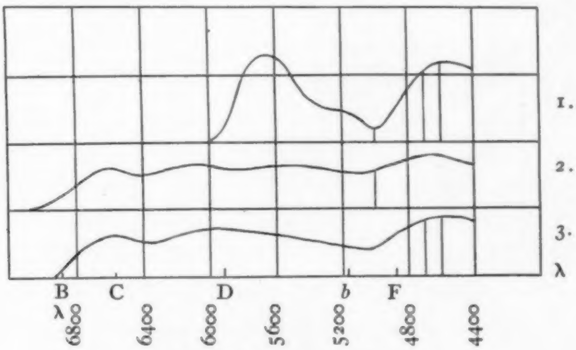
Briefly expressed, the "device" consists in sensitizing an isochromatic plate for the red, and making use of a color-filter with an absorption at λ 5000 (made by the writer). His first illustration shown represents the color curve of the Lowell 24-inch objective, but the curve shown by Lowell differs considerably from curves supplied me for the construction of his color-filters, and differs also from that published by Slipher in the *Astrophysical Journal.*[1] This lack of accordance is shown in the illustration (Fig. 8), where it will be seen that there is an ordinate difference of from 5 to $7\frac{1}{2}$ units at the Fraunhofer C and B lines. A close search fails to find anything published regarding a redetermination of the curve later than that already published by Slipher.

[1] **20**, 9, 1904.

The second illustration is entitled "curves of sensitiveness of photographic plates" (Fig. 9*a*), but as such they are unfortunately quite wrong.

Taking that one plotted as the "Cramer instantaneous isochromatic" and comparing it with the *actual* sensitiveness curve plotted from careful measurements as shown by the dotted line (Fig. 9*b*),

FIG. 9*a*



1. Cramer Instantaneous Isochromatic.
2. Seed "23": Pinacyanol and Pinaverdol bathed.
3. Seed "23": Pinacyanol and Pinachrome bathed.

(Ordinate values were not indicated.)

the result serves well to show the futility of plotting densities from visual estimates.

The two Lowell curves shown extending into the red beyond B, are marked respectively "Seed 23 bathed with pinacyanol and pinaverdol," and "Seed 23 bathed with pinacyanol and pinachrome." The context of the paper informs us that a trial of these two plates thus treated resulted in failure, the cause for which it is suggested may lie in the developer used. Inability in the present writer to follow the reasoning which prompts this suggestion, leads, however, to discarding the attempt, when it is obvious that the failure follows *inevitably* from the slowness of the plate and the "flatness" of its sensitiveness curve between λ 5000 and λ 6800. As failures, however, the value of their inclusion is doubtful, while as representing relative sensitiveness they are deficient. The "blue-sensitiveness" of a plate divided by the "yellow- (or red-) sensitiveness" is the method

adopted by all photographic workers for expressing the chromatic value; and following this, measurement of these curves gives a value of about 1.2 or 1.3, while in reality the true value lies in the neighborhood of 11.0 or 12.0.

In all probability a part of the difference is due to the fact that the Lowell curves are estimated from prismatic spectra—a most unreliable source because the apparent sensitiveness is shifted toward the red

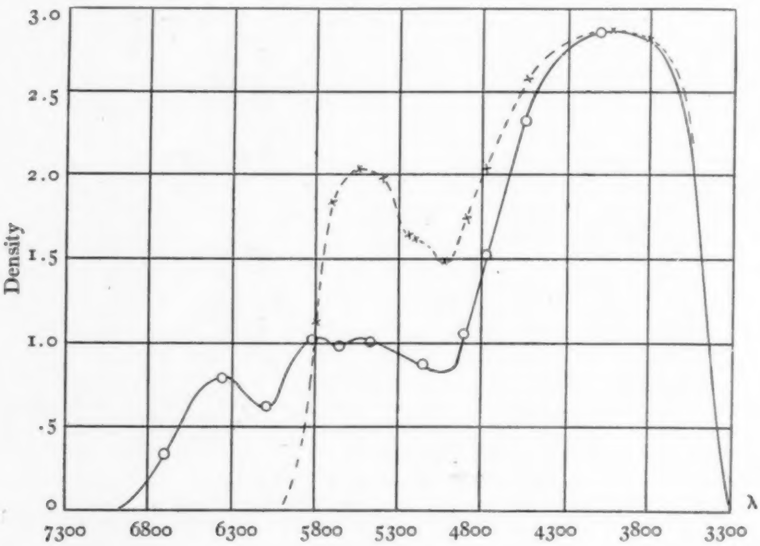


FIG. 9*b*

end by an amount dependent upon the refractive index and number of prisms used. Every investigator in photography knows that the maximum sensitiveness lies at λ 4100 not at λ 4600, and that in fast isochromatic plates of high quality the value of the yellow-green-sensitiveness is far below that of the blue-sensitiveness, and not in excess, as shown in the Lowell curves. What we are immediately concerned with, however, is the relative sensitiveness of the isochromatic plate after bathing.

If it were possible to sensitize an isochromatic plate for the red, and retain the relatively high maximum of sensitiveness in the yellow-green at λ 5100, then, in reality, we should still occupy the same position in regard to celestial photography as before; because although

it would be possible to gain greater speed it would be at the expense of definition; for it stands without possible argument, and as has been shown, that the greater the extent of objective curve embraced, the less critically sharp the image; although by consequent reduction in exposure time there would be less liability to unsharpness by waves of bad seeing. It is unfortunately true, however, that it is impossible to retain the value of the original isochromatic maximum.

Supplementary to a somewhat exhaustive investigation upon the action of the isocyanin dyestuffs upon the photographic plate recently concluded by the author,[1] about a dozen isochromatic plates were bathed in a combined bath of pinacyanol and pinachrome, under different types of bath, which included water, and dilute alcohol, plus ammonia, with subsequent washing in water, alcohol, dilute alcohol, and without washing. The strongest sensitizing action with this plate was found to result from an aqueous ammoniacal bath followed by a slight water washing, and rapid drying. The plate was then developed in the constant temperature tank, fixed, dried, measured, and plotted. This is the curve shown by the continuous line in Fig. 9*c*.

It has been suggested that, inasmuch as the objective in itself certainly possesses selective absorption, prismatic spectra were therefore very suitable, and in fact "quite the correct thing" for tests of relative sensitiveness. A series of spectra illustrating the absorption of the 40-inch objective (Fig. 10, Plate IX) shows, however, that beyond an absorption of about 200 Å. in the extreme ultra-violet there is no shift in the point of maximum sensitiveness, which remains constant at λ 4100. In previous papers the writer has demonstrated with some degree of completeness the incomparability of prismatic and diffraction spectra.

Inasmuch as we are mainly concerned at present with the action of the plate under a color-filter, a series of exposures was also made through a λ 5000 filter (precisely similar to that made for Professor Lowell) to the spectrum of diffused daylight, and the normal exposure measured and plotted. Similar exposures were also made upon the pinacyanol and pinachrome bathed "iso" plate, which was also measured (for equal-exposure times). These exposures, together with their resultant measured curves, are now shown in Fig. 11.

[1] *Astrophysical Journal*, **26**, 299, 1907.

Measurement of the relative areas of these curves gives a result which is practically equal.

Exact tests are desirable, however, to determine the remaining constants of the plate, and to that end two isochromatic plates (bathed and normal) were exposed simultaneously in the revolving sector-disk machine behind the λ 5000 filter to diffused daylight. Both

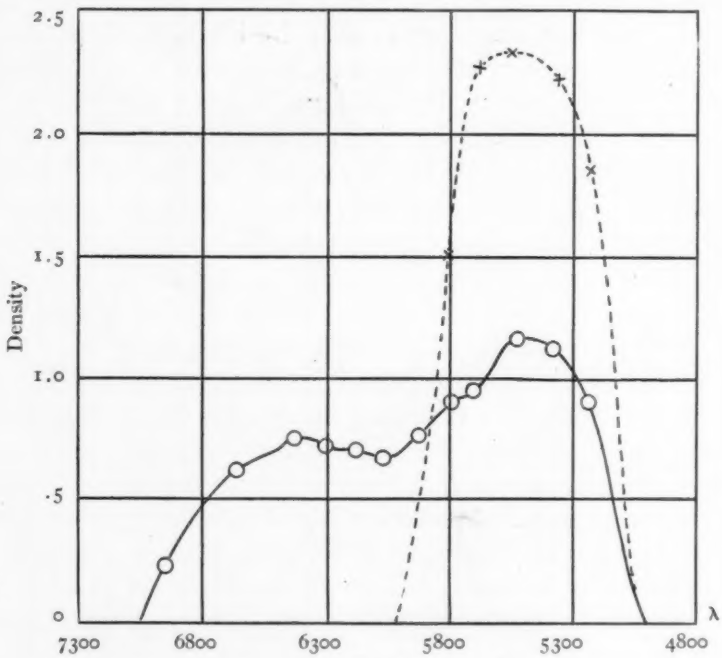


FIG. 11

plates were developed together at the one time, for the same length of time, and at constant temperature. They were then measured, and their curves are shown in Fig. 12.

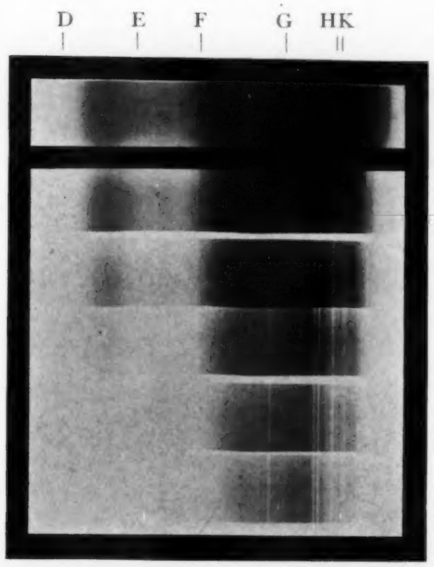
Parallelism of the curves instantly indicates no change in gradation by bathing, while the extraction of the relative speed gives a value of 1.1 times, or 10 per cent. in favor of the bathed plate. As this is a negligible amount in plate density, it therefore confirms, by direct measures to selective light, the speed estimate obtained from the spectrum curves. Flat reproductions are also shown of the plates measured. It results therefore that there is no direct gain in speed

PLATE IX

a

FIG. 10

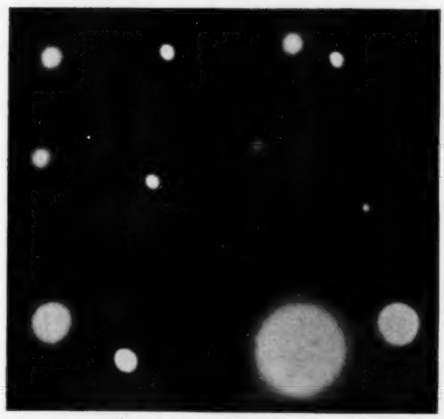
b



a. Cramer instantaneous isochromatic. unscreened.

b, Varying exposures through 40-inch objective to same sky as in *a*, and showing absorption in ultra-violet.

FIG. 7

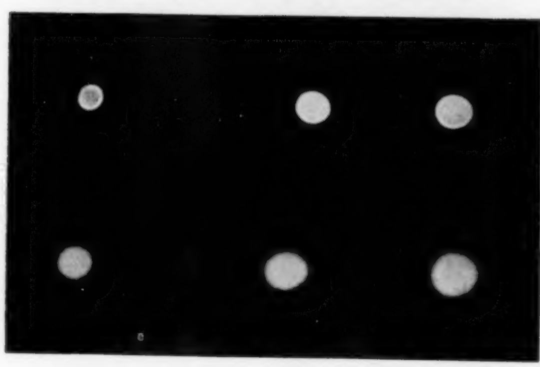


Difference in quality of star images with color-filters absorbing at λ 4600 and λ 4900 respectively.

a

FIG. 13

b



Star images with 40-inch telescope photographed under identical conditions of "seeing", focus, exposure time, and color-filter (λ 4950) but upon (*a*) isochromatic and (*b*) red-sensitive plate.

but merely extension of spectral sensitiveness, the effect of which will be presently shown.

Taking up the "tests" by Lowell, I quote from *Lowell Observatory Bulletin*, No. 31, as follows: "Exposing a plate of this kind on *Mars*, in our usual way, ... I took half the number behind the old screen and then replacing it by the new one, took as many more, both sets

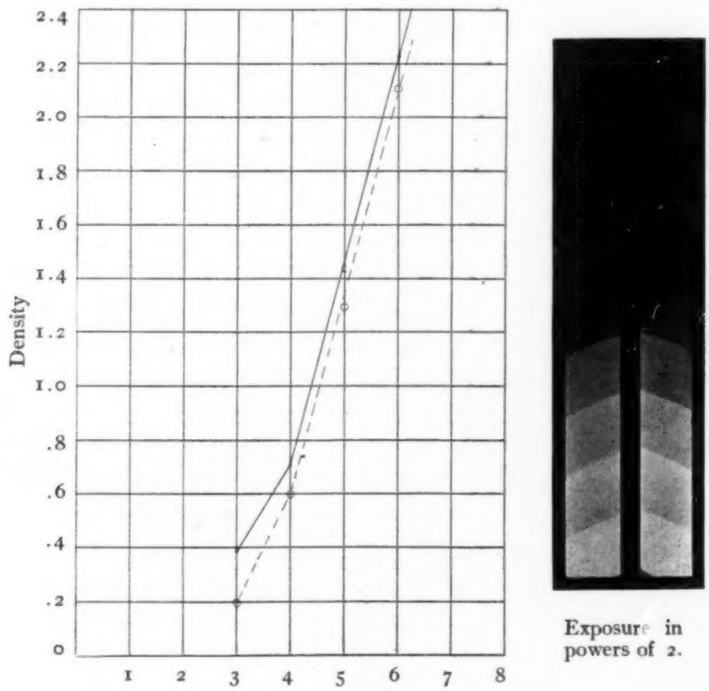


FIG. 12

being exposed equally. . . . . The results stood self-confessed, the detail came out sharper in the images taken with the orange screen than with those taken with the yellow. . . . ."

It would have been rather astonishing had the result *not* shown a difference; for when we consider that we are dealing with two entirely different color-filters, one of which transmits to λ 4800 and both of which are constructed for use with a plate possessing *one* single high maximum in the yellow-green, it would hardly be expected that they should give as sharp results when used with a plate possessed of *two*

active maxima. A more complete knowledge of the underlying principles would have predicated the result obtained. Had the λ 4800 filter been intended to be used on such a type of plate, then it would have been made to absorb the red end also.

That an extended sensitiveness does not compensate for a single maximum, is very well shown in the accompanying illustration (Fig. 13, Plate IX), which represents a series of (*a*) three exposures with the 40-inch telescope upon an instantaneous "iso" plate through a color-filter, at the critical focus; and (*b*) three more exposures upon the same star, through the same filter, for similar lengths of time, at precisely the same focus, with estimated identity of seeing, *but with a red-sensitive plate.* The increase in the size of the images, and the loss in sharpness, is readily apparent and needs no further comment.

If instead of a star we assume the case of the planet *Mars*, then we should have still a more decided example, because, according to Slipher, "the continuous spectrum of *Mars* is decidedly stronger in the orange red than that of the moon, while at E the reverse is true,"[1] whence an increased action in the out-of-focus red.

In making use of the color-filter λ 4800 with a red-sensitive plate, use is being made of more than double the amount of out-of-focus light than would be effective if the filter were used with the plate for which it was solely constructed; for, by the lowering of sensitiveness in the original isochromatic maximum, there is an increase in the burden of action which is thrown, first, upon the amount of blue light transmitted by the filter, and second, upon the region of enhanced sensitiveness at the red end, which is, equally with the blue, upon a rising branch of the objective's color curve.

With the orange filter the blue is cut off entirely, confining the action to the yellow-green and red, i. e., to the flat portion and a *single* rising branch, therefore a step nearer monochromatic conditions. Were the action taken entirely out of the red and *added to* the yellow-green, it would be a step still nearer true monochromatism, but such a change would result simply in practically duplicating the original compensated curve of the instantaneous isochromatic plate (see Fig. 11). It therefore follows, and is beyond the possibility of

[1] *Lowell Observatory Bulletin*, No. 17.

doubt, that if this filter be used in conjunction with the instantaneous "iso," still sharper images will be obtained than with the red-sensitive plate, because the active rays will be more nearly monochromatic.

The value of exposure combined with steadiness of air as influencing sharpness, (1) by reason of monochromatism of light acting, and (2) by only making use of a minimum disturbance, is shown by the excellence of direct solar negatives made with the blue light on ordinary non-orthochromatic plates, at a point where the color curve is rapidly approaching the vertical.

Important as is the correct appreciation of the isochromatic plate, color-filter, and exposure, yet of an importance equally commensurate is the rôle played by an efficient backing. It is safe to state, that in the delineation of astronomical detail the omission of backing causes at least a 50 per cent. loss of presentable results; while in each instance where such results have been attained, they would have been 100 per cent. better had backing been used. It is equally safe to say that the lack of knowledge on this point is even greater than on the chromatic adjustment of plate and filter, and yet the principle involved is of obvious comprehension.

Everyone who has photographed (and many who have not) has observed that where, for example, an exposure has been made upon a subject presenting fine dark markings upon a brightly illuminated area, in many instances this detail is either entirely obliterated or so grievously weakened as to be decipherable only with difficulty. In ordinary outdoor views branches or other objects cutting the bright sky are equally lost. This is the most common effect of *halation*. It is well known that when a ray of light after passing through the sensitive film and glass plate at any angle other than normal meets the air at the surface common to both, a portion of the ray is reflected again into the glass and impinges against the lower surface of the sensitive film. This amount of light reflected gradually increases with the angle of incidence until it reaches the critical angle at which point there is total reflection. The point upon the sensitive film where the ray falls may be considered as a point of emission and as the rays radiate in all directions around this point they thus form a circle in the plane of the sensitive film. This halation circle is very evident in photo-

graphic stellar negatives which have been made on *un*backed plates.[1]

In astronomical photography of an illuminated area such as the moon or the planets we have a precisely similar effect, for if on this illuminated area there be visually noted a thin or faint line, then the difficulty of recording it upon the sensitive film (even assuming absolute steadiness) is enormously increased if the plates used be not backed. Let *A* (Fig. 14) represent diagrammatically a section of the sensitive film and *B* the glass support, then the film at the narrow line *D* is (theoretically) unacted upon, while the illuminated area at *dd'* is, and is blackened by the subsequent action of the developer. If the plate be unbacked the rays illuminating the area *dd'* are refracted as in *d''* through *A* and *B*, and reflected back to the lower sensitive surface *P*, where they react upon the film, and upon development produce a blackening which in itself is sufficient not only to obscure but often entirely to obliterate the impress of the narrow line-image *D*.

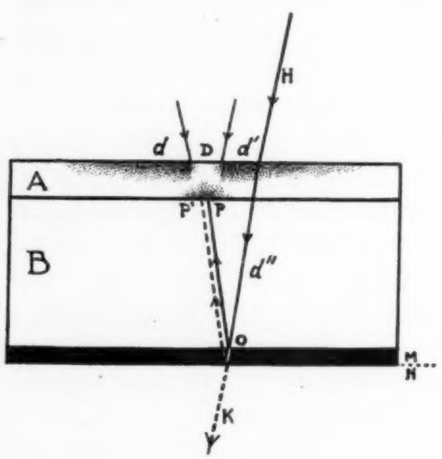


FIG. 14

It will of course be evident that if there be no variation in refractive index in the course of the path of the beam *HK*, there can be no reflection at *O*, hence no deposit at *P*. It follows, then, that if the plate be backed with a medium of similar refractive index to the glass, the beam will pursue its path without suffering reflection, provided that this medium be of such a color that it absorbs the active light-rays when they have entered.

If the layer of backing applied to the glass be represented at *M*,

[1] There is another form of halation caused by the spreading of the light laterally through the film, but inasmuch as this is a matter over which the photographer has no control, and is of very small effect, it is not necessary to consider it here.

then it results that the path of the incident beam H continues uninterruptedly until it reaches the air surface at MN, from whence it would be reflected to O'. However, if the layer M be colored red, then the light-rays will, by absorption, be robbed of their actinic value, so that only red light will be returned to P, which are of course inactive upon the film.

In practical work a backing composed of caramel mixed with a quantity of burnt sienna, or lampblack, has been found highly efficient. The compound is smeared heavily over the back of the plate with a stiff bristle brush.

When use is made of red-sensitive plates it would obviously be of no avail to color the caramel red because the modicum of light returned would be that to which the plate was sensitive, hence the best result for general work will be attained by the use of black. A damp wad of absorbent cotton readily removes the backing before development. [1]

To be most thoroughly effective, the backing should be in contact with the sensitive film and between it and the glass support. Such plates with a stained substratum are manufactured by several firms, but deficiency in the relative sensitiveness of the film has—so far—eliminated them from use in astronomical work.

In concluding these remarks upon the influence of filters and isochromatic plates in astronomical photography, no claim is made for general originality; in the specific application to astronomy the *treatment* is new, but otherwise all points are matters of common knowledge to the photophysical student.

We may summarize the foregoing in the following few sentences:

1. It is axiomatic that the closer the approach to monochromatic illumination, the more critically sharp will be the image. In practice the approach to monochromatic conditions is governed by the sensitiveness of the plate to the region under consideration.

2. With the use of the commercial isochromatic plate with its single secondary maximum in the yellow-green, there is no certain improvement in photographic definition (astronomically considered) by making use of a color-filter of greater mean absorption than λ 4900–λ 5000.

[1] If the plate be laid aside for some time before development the backing should be removed as its presence results in peculiar markings upon the film.

3. The two governing factors in successful astronomical photography of faint detail on illuminated areas (such as lunar or planetary work) are first, critical minimum exposure; and second, effecevti backing.

4. Given the necessary apparatus and material and assuming the ordinary ability to handle it, the personality of the operator exercises no influence upon the results obtained. These are, instead, relatively good or bad, as the "seeing" is excellent or poor.

YERKES OBSERVATORY
December 23, 1907

PLATE X

K H 4226.9

FIG. 1

FIG. 2

FIG. 3

b

a

K H 4226.9

REVERSALS OF CALCIUM LINES

DETERMINATION OF THE ORBITS OF SPECTROSCOPIC BINARIES

By W. F. King

On the assumption that the orbit of the star is an ellipse described about a center of force in one focus, the graph formed by taking the velocities in the line of sight as ordinates and the corresponding times as abscissas will be a periodic curve, from which can be determined the elements of the orbit, viz., the periodic time, the eccentricity, the longitude of the periastron from the ascending node, the projection of the major axis upon the line of sight, and the velocity of the system as a whole, that is, of the center of gravity of the system or of the focus of the elliptic orbit.

Various methods of determining these elements have been given, either geometrical, like that of Lehmann-Filhés, depending upon the comparison of areas of certain parts of the curve; or analytical, like that of Russell, using a Fourier series.

The curve of observed line-of-sight velocities differs from the true curve, by reason of errors of observation. The method of least squares may be employed to correct the first values of the elements, and to give the most probable values.

Spectra of certain types, however, are difficult to measure with accuracy, with the result that the graph of observed velocities may present differences from the theoretical curve which bear a considerable ratio to the velocity, so that the method is not to be depended upon unless successive approximations are made, entailing much labor. In such cases correction of the graph may be resorted to.

A free-hand curve is drawn, as nearly as possible of the form which the velocity curve should have, and as nearly as possible representing the observations. This curve may be adjusted so as to fulfil certain theoretical conditions, as to equality of areas, etc. (Lehmann-Filhés method). From this curve the elements are determined and from them an "ephemeris" is computed and a new graph representing these elements is drawn. Comparison of this with the former curve indicates correction to the elements, whereby a better accord-

ance with observations may be secured. A new ephemeris with corrected values of the elements is then made, followed by a comparison with the observations. By successive trials in this way, the values of the elements most nearly according with the observations are finally determined. This is the method which has been fol-

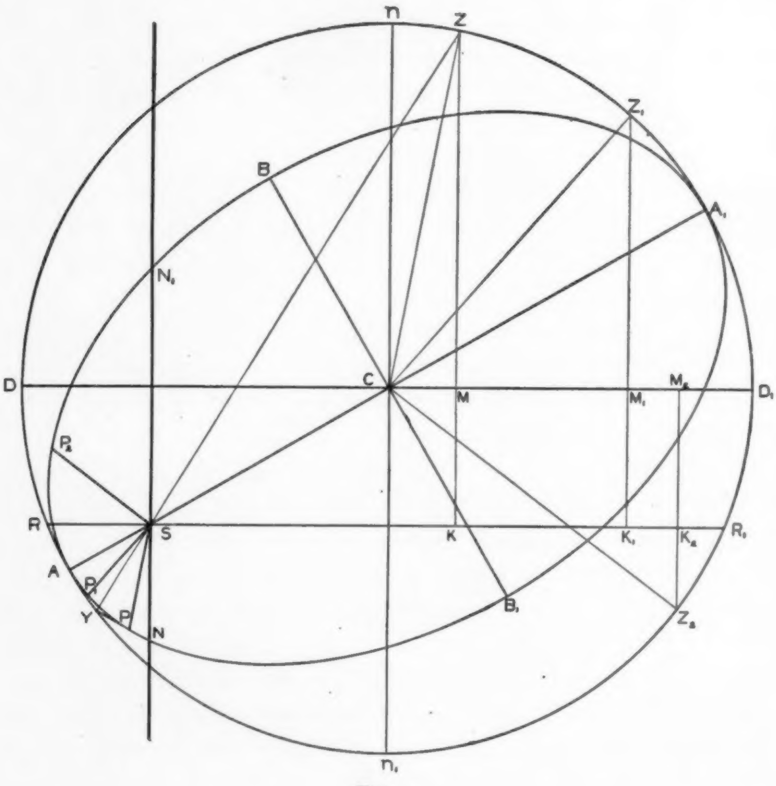


Fig. 1

lowed here in obtaining the elements of the orbits of early type stars, and I notice by some orbits recently published by the Lick Observatory, that the same procedure has been adopted there.

The object of the present paper is to present a method whereby as much as possible of the work of testing the accuracy of the successive graphs and of preparing the ephemerides may be done graphically.

Let the ellipse ABA_1B_1 in Fig. 1 represent the orbit of the star, S the center of force at the focus, AA_1 the major axis, N the ascending node, N_1 the descending node. Let P be the position of the star in its orbit at any time. We will suppose the motion of P to be clockwise. Draw SY perpendicular to the tangent at P. The point Y will, by a property of the ellipse, fall on the circle AZZ_1A_1, described on the major axis as diameter. If h is twice the area described in the unit time, v the velocity of the body in its orbit (with reference to S considered fixed). And if we produce YS to meet the circle again in Z,

$$SY \cdot SZ = SA_1 \cdot SA = a^2(1-e^2).$$

Hence

$$v = \frac{h}{a^2(1-e^2)} \cdot SZ .$$

SZ therefore is proportional to the velocity at P. It is perpendicular to its direction. Therefore the circle AZZ_1A_1 is the hodograph of the orbit, changed in scale in the ratio $1 : \frac{a^2(1-e^2)}{h}$ and turned through a right angle.

Draw RSR_1 through S, and DCD_1 through the center C, perpendicular to the line of nodes. Draw ZMK perpendicular to these two lines and cutting them in M and K. Then ZK is proportional to that component of the velocity relative to S, which is perpendicular to the line of nodes and in the plane of the orbit. If the plane of the orbit is inclined to the line of sight at an angle $90° - i$, $ZK \sin i$ is proportional to the velocity in the line of sight.

Multiplying all the ordinates, as ZK, of the circle by $\sin i$, we evidently find for the hodograph of velocities in the line of sight an ellipse, of which the semi-major axis is proportional to CD or a, and the semi-minor axis to $a \sin i$.

It is to be observed that, by a property of the ellipse and the circle on its major axis CZ is parallel to SP. When therefore P proceeding from the ascending node has turned an angle u about the focus, the corresponding point of the elliptic hodograph has the eccentric angle u (counted from the minor axis). The velocity in the line of sight (still considering S at rest) is therefore

$$(ZM + MK) \sin i = a \sin i \cos u + MK \sin i.$$

This consists of a constant part $MK \sin i$ which is equal to $SM \sin i \cos \omega$ (ω denoting the longitude of the apse counted from the ascending node) or $ae \sin i \cos \omega$; and a variable part $a \sin i \cos u$.

Let us now conceive the scale of the figure to have been changed by multiplying all lines in it by $\frac{h}{a^2(1-e^2)}$; then the circle AZZ_1A_1

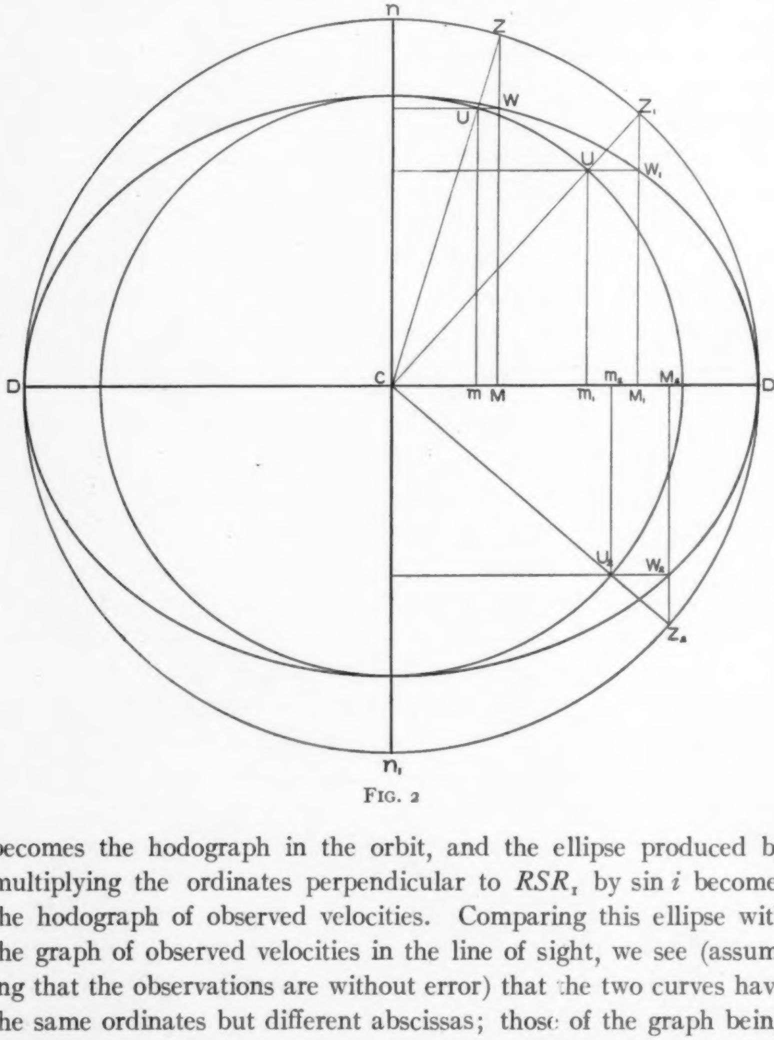


FIG. 2

becomes the hodograph in the orbit, and the ellipse produced by multiplying the ordinates perpendicular to RSR_1 by $\sin i$ becomes the hodograph of observed velocities. Comparing this ellipse with the graph of observed velocities in the line of sight, we see (assuming that the observations are without error) that the two curves have the same ordinates but different abscissas; those of the graph being proportional to the time, those of the ellipse being proportional to

the sine of the eccentric angle counted from the minor axis, that is, to the sine of the longitude (u) counted from the periastron.

Fig. 2 shows by the circle AZZ_1A_1 the orbital hodograph, and by the ellipse AWW_1A_1 the hodograph of the line of sight, having the ordinates MW, M_1W_1, etc., equal to $MZ \sin i$, $M_1Z_1 \sin i$, etc. Reduce all the abscissas of the ellipse in the same ratio, multiplying by $\sin i$. Then the ellipse becomes the circle UU_1U_2 described on the minor axis as diameter.

By consideration of the similar triangles ZMC, UMC, etc., it is seen that the new positions U, U_1 . . . . of the points W, W_1, W_2 fall on the straight lines joining C with Z, Z_1, Z_2, etc. Therefore the longitudes are unchanged, and the circle U, U_1, U_2, may be used as the equivalent of the hodograph of observed velocities. The problem is reduced to comparison of a circle with a curve in which the abscissas are proportional to the time.

The radius of this circle may be denoted by K. In terms of the elements of the ellipse

$$K = a\frac{h}{a^2(1-e^2)}\sin i = \frac{h \sin i}{a(1-e^2)}\ .$$

h is found from the periodic time U, for

$$h = \frac{2\pi a^2\sqrt{1-e^2}}{U}\ .$$

$$\therefore K = \frac{2\pi a}{U\sqrt{1-e^2}}\sin i.$$

K is equal to one-half the difference between the maximum and minimum velocities in the line of sight. When this and e have been found with the desired precision, the value of $a \sin i$ follows from the above formula. Figs. 3 and 4 will serve to illustrate the application in practice of the foregoing principles.

First of all, the observed velocities having been plotted as ordinates with the times as abscissas, a free-hand curve is drawn approximately of the peculiar form of the theoretical curve, and passing through or near to the points representing the individual observations. The curves in the figures may be taken as representing more or less closely such a graph of observations. In the figures the curves have been drawn with exactness for two eccentricities, 0.75 and 0.10.

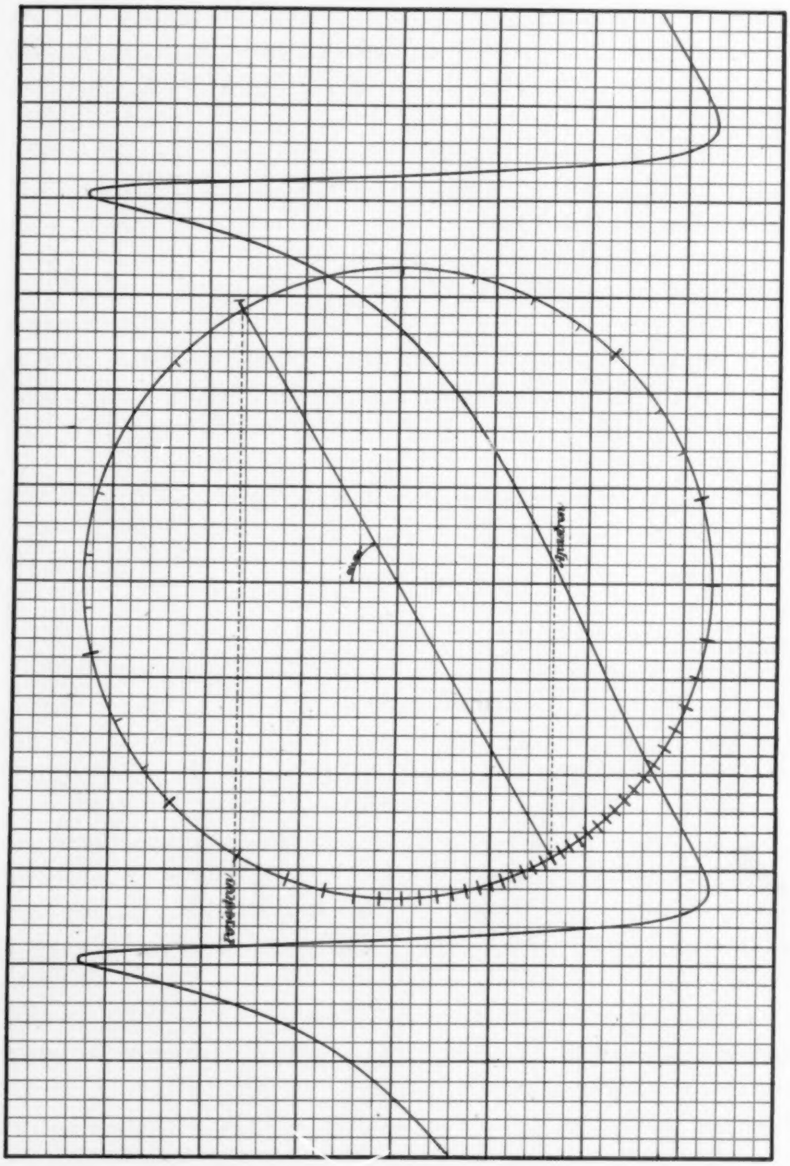


FIG. 3.—Graph for $e = 0.75$, $\omega = 60°$.

A circle is drawn having for diameter the difference between the maximum and minimum ordinates, and having its center on the line midway between the maximum and minimum points. This line, parallel to the axis of abscissas, may be called the central line of the curve.

The periodic time having been determined in the usual way, the abscissa-length corresponding to it is divided into any convenient number of equal parts, say 40; it should be an even number. The ordinates for these abscissas are placed in the circle, and the points so found in the circumference of the latter are marked. If the curve is of correct form, the points marked on the circumference will be found to lie at unequal distances from one another (except when the eccentricity of the orbit is zero), but these unequal distances will be found to vary uniformly. The points will be close together in the vicinity of one point of the circle, and will gradually separate as we proceed in either direction therefrom, until at the diametrically opposite point they reach their maximum distance apart. It is evident that the former point will correspond to apastron, and that of widest separation to periastron.

If it chances that one of the points of division of the line of abscissas corresponds to an apse, the divisions of the circumference will be equal at equal distances from the apsidal diameter. It not, f they will not be equal on the two sides of this diameter, and the periastron will not coincide exactly with a division, but will lie within the greatest division of the circumference. Apastron similarly lies within the least division. We may, if we please, use the approximate positions of the apses thus found to set off our fortieths of the period along the line of abscissas from a new origin, whereby two of the points of the circle will more closely coincide with the apsidal points. In this manner, given a graph sufficiently near to the theoretical form, the position of the apsidal diameter may be determined and the angle which it makes with the axis of y measured with a protractor. This angle is the longitude (ω) of the apse.

It will be observed that this process furnishes a more thorough test of the accuracy of the graph than the method of equality of areas. If it is imperfect, the points on the circumference of the circle will not be distributed according to the regular order of increase

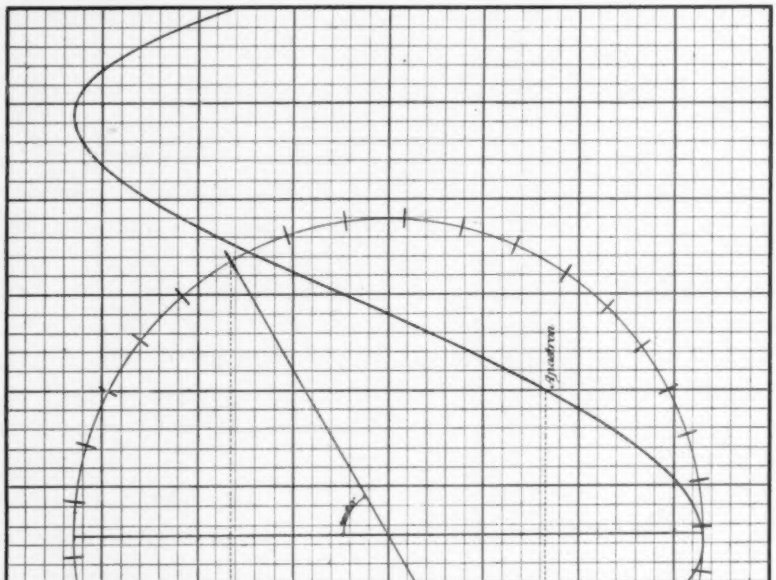


FIG. 4.—Graph for $e = 0.10$, $\omega = 60°$.

or decrease of the included arcs. If an ordinate of the graph is too long or too short, the corresponding point on the circumference will be too near or too far from the vertical diameter.

If the points of maximum and minimum velocity have not been well determined, the diameter of the circle will be too long or too short. In the former case all the points on the circumference will be crowded away from the vertical diameter; in the latter, toward it. Since the arcs of the circle represent differences of longitude corresponding to the given intervals of time, and $\frac{du}{dt}$ varies inversely as the square of the distance from the focus, we have by measuring the lengths d and d_1 of the arcs at points whose longitudes from the periastron are θ and θ_1,

$$\frac{d}{d_1}=\frac{(1+e\cos\theta)^2}{(1+e\cos\theta_1)^2},$$

whence the eccentricity may be found, when the position of periastron is known. If we measure the arcs at periastron and apastron, we have

$$\frac{d}{d_1}=\left(\frac{1+e}{1-e}\right)^2.$$

In applying this method, it is usually sufficient to measure the chords instead of the arcs, as only an approximation is needed at this stage. If the eccentricity is so large as to so greatly increase the arcs near periastron that they may not be considered equal to their chords, additional points may be interpolated near periastron.

It is not advisable, however, to spend too much time on these preliminary processes, as it is hardly possible that the first graph should be drawn with sufficient accuracy to give a good final result. The approximate value of the longitude of the apse and the eccentricity is, however, needed for the construction of a better graph, or "ephemeris."

The process in use here of approximate determination of the elements and constructing an ephemeris is as follows: Using the analytical formulae, the true anomalies corresponding to aliquot parts of the period of the binary are computed for any assumed eccentricity, and set off on the circumference of a circle, to be used as a protractor. A division of the period into 40 equal parts is in

general convenient, though for high eccentricities a further subdivision must be made for the neighborhood of periastron. The need for this is shown in Figs. 5, 6, and 7, which show protractors drawn for eccentricities 0.70, 0.75, and 0.80 respectively. The anomaly corresponding to one-fortieth of the period (or 9° of mean anomaly) is seen in Fig. 7 to be almost 90°. Intermediate lines near periastron have therefore been interpolated (shown dotted in the figures), dividing the one-fortieth next to periastron into 6 equal parts, each corresponding to 1°.5 of mean anomaly (this is found convenient with the tables we use, which give the solution of Kepler's equation for every half-degree). The second interval from periastron has been divided into 3 equal parts (3° of mean anomaly).

In Figs. 8, 9, and 10, drawn for small eccentricities, 0.05, 0.10, and 0.15 respectively, the parts of the circumference are nearly equal throughout. A number of these protractors, on transparent celluloid, have been made here. After the ordinates of the curve have been transferred to the circle, and the circumference marked off, a choice among the protractors will show which one agrees most closely with the marked points, and thereby the values of the longitude of the apse and the eccentricity of the orbit are obtained. Tests here have shown that the eccentricity can thus be determined within 0.01 when the velocity-curve is accurately drawn. If not accurately drawn, no such close approximation is necessary.

To construct an ephemeris, given eccentricity e, apse longitude ω, range of velocity $2K$, and period U, proceed as follows:

Draw a circle of radius K. Draw its "vertical" and "horizontal" diameters, producing the latter to the length necessary for the period U, according to the time-scale adopted. Set the protractor, made for eccentricity e, with its center over that of the circle, and its apsidal diameter making an angle ω with the vertical diameter. Plot the radial lines representing the anomalies corresponding to the divisions of the period upon the paper, noting their intersections with the circumference.

Having divided the line representing the period into a number of parts corresponding to the protractor, erect perpendiculars at these points of lengths equal to the corresponding ordinates of the circle. A free-hand curve drawn through the extremities of the ordinates gives

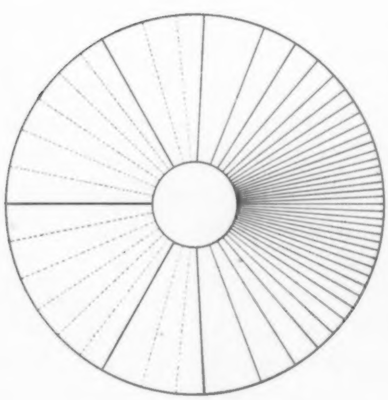


FIG. 5. $e=0.70$.

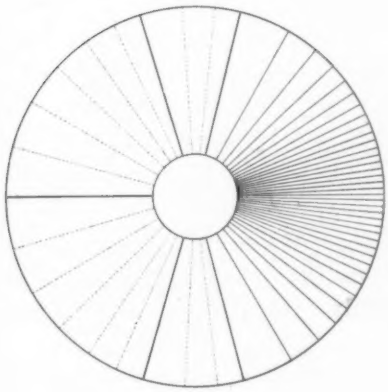


FIG. 6. $e=0.75$.

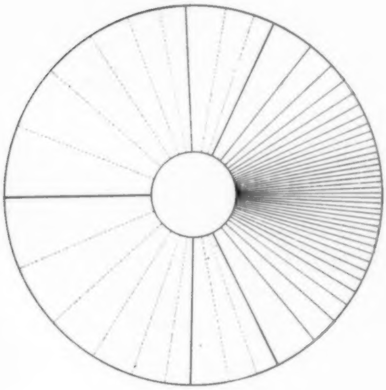


FIG. 7. $e=0.80$.

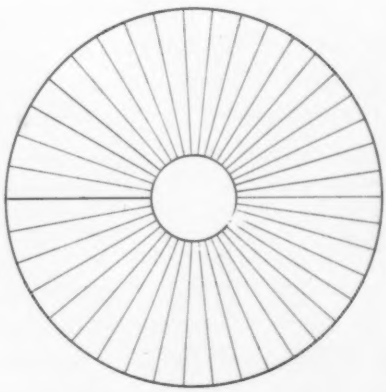


FIG. 8. $e=0.05$.

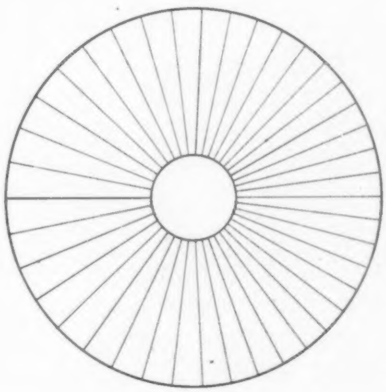


FIG. 9. $e=0.10$.

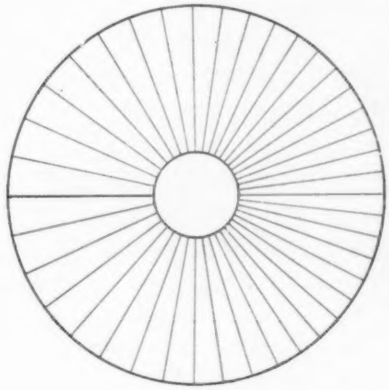


FIG. 10. $e=0.15$.

the required curve or "ephemeris." If, as will usually happen, the observations are plotted and the graph drawn on cross-section paper, the procedure will be considerably shorter. Draw the circle of radius K on the same or a similar sheet, place centrally on it the transparent protractor with the periastron point at the proper longitude ω from the vertical diameter, and note the ordinates of the points of intersection of the circumference of the circle with the radial lines of the protractor. These ordinates can be at once placed on their corresponding abscissas without either drawing or measuring.

If a set of protractors, such as in use here for values of e differing by 0.05, is not available, an alternative procedure is to use an ordinary protractor to set off arcs of 10°, say, and then the abscissas of the time velocity curve may be made equal to the mean anomalies corresponding to true anomalies of every 10° around the orbit. This can easily be done with a set of tables, such as have been computed here, giving the parts of the period corresponding to true anomalies of every 10° for all values of e from 0 to 1, at intervals of 0.05.

When the ephemeris has been drawn, it may be redrawn to a different apsidal longitude in the manner following. In Fig. 11, draw CA and CB equal to the radius K of the generating circle, and including an angle (β) equal to that by which it is desired to change the apse-longitude. It is evident that if the point C be placed on the central line of the curve, and A on any point of the curve, the point D where the ordinate of A meets a line through B parallel to the axis of abscissas will be a point on the curve corresponding to an orbit, of the same eccentricity e, and apse-longitude $\omega+\beta$. For if the ordinate of A is $K \sin(\theta+\omega)$, θ being the true anomaly, that of D will be $K \sin(\theta+\omega+\beta)$, and the abscissa (the time) remains the same.

To decrease the apse-longitude, set B on the curve and find the point D_1 on the ordinate of B, such that AD_1 is parallel to the axis of abscissas.

In practice a curve may be converted very rapidly. Let the construction be made on cardboard. After drawing the lines CA and CB, describe a circle on AB as diameter. Cut this circle out of the cardboard, marking on its circumference the point A. Cut the cardboard so that there is a tolerably sharp point at C. If the curve

has been drawn on cross-section paper, the intersection of the ordinate of A can be followed down by eye to its intersection with the circumference at D, and this point marked with a pencil. By operating thus with a number of points the curve can very rapidly be drawn to the changed apse-longitude.

If it is desired to change the scale of the velocities (i.e., the value of K) and the apse-longitude at the same time, this may be done by a slight modification of the construction above. Draw CA (Fig. 12) as before equal to K and $CB=K_1$ at an angle β with CA (to

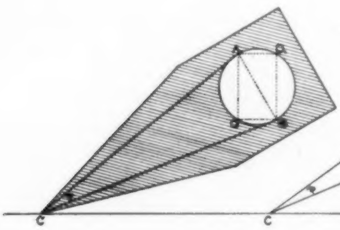


FIG. 11

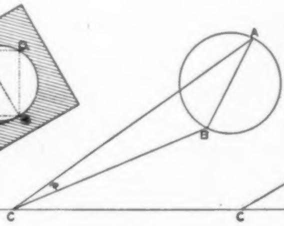


FIG. 12

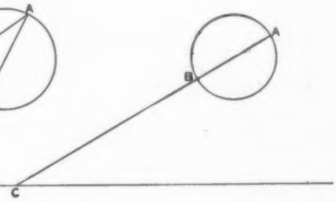


FIG. 13

right or left according as increase or decrease of apse-longitude is required). Draw the circle on AB as diameter, and proceed as before to draw the amended curve.

If it is desired to change K to K_1 without changing ω, CA and CB are drawn in the same line (Fig. 13) and the circle is described on the diameter AB as before.

These constructions suggest another method of drawing an ephemeris.

Let a number of standard curves be drawn for different eccentricities, and for any convenient apse-longitude, which may be 0 or 90°, or have any other value. Such a curve will differ from the graph of the observations both in the scale of the abscissas and also in that of the ordinates, and in general in different ratios.

Both abscissas and ordinates may be reduced with the pantagraph to the scale of abscissas set by the length of the period of the binary, and then the further change of scale of ordinates to agree with that of the observed velocities may be made in the manner outlined above, and at the same time any required apse-longitude

may be introduced. This method would have the advantage that the standard curve for a given eccentricity would need to be drawn but once, and therefore might be constructed very carefully. No convenient method of varying the eccentricity has yet been devised.

I wish to express my obligations to Mr. J. S. Plaskett for valuable assistance in preparing this paper for publication.

Dominion Astronomical Observatory
January 31, 1908

THE STAR IMAGE IN SPECTROGRAPHIC WORK. II

By J. S. PLASKETT

In the paper under this title published in this JOURNAL for April 1907, I described a series of tests made to determine the character of the image given by the system of visual objective with auxiliary photographic corrector, which is so generally used as the condensing system in spectrographic work. These tests definitely proved that the resulting image had negative aberration, that the focus for the edge rays was about 2.5 mm longer than the focus for central rays. It was also shown that the chromatic difference of spherical aberration of the objective at H_γ accounted for about 2 mm of this aberration, and that the correcting lens instead of removing the difficulty had added to it. Furthermore, a comparison of the relative exposure times at Ottawa with those of other equipments showed that the same difficulty probably existed elsewhere.

The matter, therefore, was deemed of sufficient consequence to justify an energetic attempt to improve the quality of the image and a new corrector was ordered from the J. A. Brashear Co. As the difficulty with the original corrector had been partly ascribed to its small size, 2.25 inches (57 mm) aperture, Professor Hastings enlarged the new lens to 4 inches clear aperture, with an effective aperture of 3.8 inches (96.5 mm). As it was impracticable to send the objective to Allegheny for use in testing the corrector, Professor Hastings devised an ingenious method of obtaining the correct figure. The radii of the surfaces and the thicknesses of the two elements were so computed that, assuming truly spherical surfaces, the system of objective and corrector would be free from aberration at the desired region. As spherical surfaces can be readily tested, the concave at the center of curvature and the convex, which in this case are of the same radius as one of the concave, by interference fringes, it was hoped that the new lens would give satisfactory images.

When it was received early in August last, it was found necessary, owing to its considerable distance, 15×3.8, or 57 inches (145 cm), within the focus, to add a support to the upper end of the mounting

in the form of a guiding ring into which the tube containing the corrector slipped. This ring was held in position and adjusted exactly in the optical axis by three radial bolts with nuts on the outside of the telescope tube. Accurate collimation after removal and replacement and also in every position of the telescope was therefore insured.

An examination of the appearance of the illumination pattern on the collimator and camera lenses, as observed by looking into the camera, sufficed to show that aberration was still present. The pattern was by no means uniform, although exhibiting some improvement over that given by the old lens.

As soon as possible the actual form of the image was determined, exactly as described in the former paper, by Hartmann's method of extra-focal measurements. The mean of a number of such measurements is given in Table I while the zonal differences of focus are platted in curve *B*, Fig. 1. For comparison the curve for the original corrector is reproduced in *A*, while *D* gives the differences of focus for the objective used visually.

TABLE I

ZONAL FOCI OF OBJECTIVE AND NEW CORRECTOR

Radius of Zone mm.	ϕ	New Correcting Lens			New Correcting Lens Refigured		
		Focus	Mean	Astigmatism	Focus	Mean	Astigmatism
28.......	45°	91.07		+0.26	91.87		+0.25
	135	90.55	90.81	−0.26	91.36	91.62	−0.26
47.......	0	91.55		+0.13	91.65		−0.21
	90	91.30	91.42	−0.13	92.07	91.86	+0.21
66.......	45	91.04		+0.22	91.28		+0.20
	135	90.60	90.82	−0.22	90.89	91.08	−0.19
85.......	0	90.66		+0.07	90.27		−0.10
	90	90.53	90.59	−0.07	90.47	90.37	+0.10
104......	45	91.01		+0.30	90.46		+0.14
	135	90.41	90.71	−0.30	90.18	90.32	−0.14
123......	0	91.14		+0.12	90.33		+0.04
	90	90.90	91.02	−0.12	90.25	90.29	−0.04
142......	22.5	91.28		+0.03	90.38		+0.12
	67.5	91.41		+0.16	90.24		−0.02
	112.5	90.94		−0.31	90.04		−0.22
	157.5	91.36	91.25	+0.11	90.37	90.26	+0.11
160......	45	91.85		+0.25	90.28		+0.08
	135	91.36	91.60	−0.24	90.11	90.20	−0.09
178......	0	92.43		+0.15	90.50		+0.37
	90	92.14	92.28	−0.14	89.76	90.13	−0.37

It is evident from a comparison of the curves for the two correcting lenses that the same trouble exists in the new lens as in the old, for, although there is some slight improvement, it does not yet compensate for the chromatic differences. Its curve, however, is more regular and is nearly similar to the visual curve and this, taken in conjunction

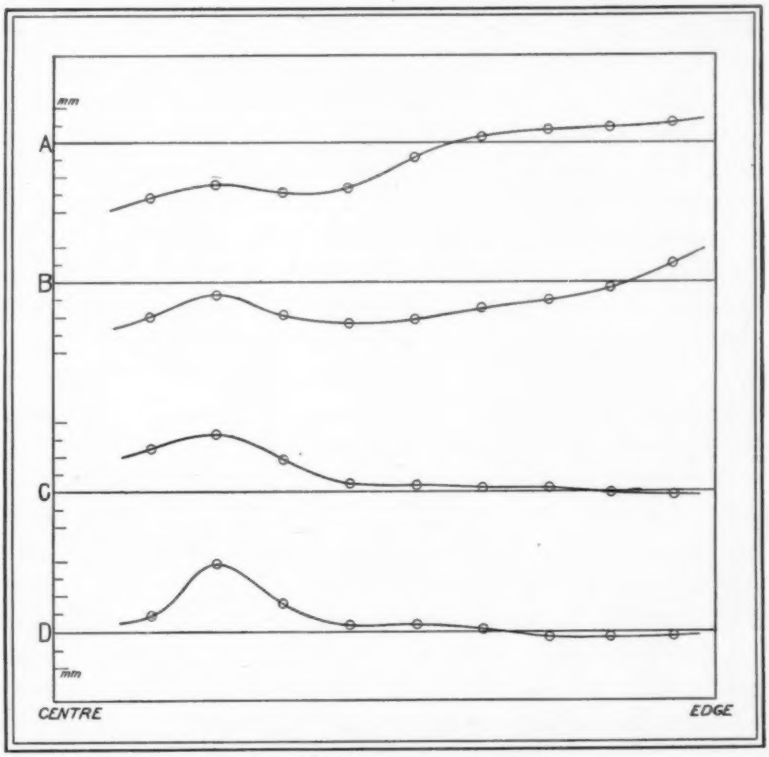


FIG. 1.—Zonal differences of focus.

with its larger aperture, should allow it to be more readily corrected by refiguring. In actual use, however, it is doubtful whether much improvement would be noticed on account of the greater inclination of the curve at the outer zones, which have the greatest effect in determining the character of the image. This disappointing failure to fulfil the computed results must doubtless be ascribed to the small unavoidable departures of the actual from the computed radii of curvature, thickness, etc., of the elements, which may easily

account for the small remaining aberration. The only chance of improvement appeared to be in refiguring the surfaces to introduce the required amount of positive aberration. A reference to Fig. 1, curve *B*, shows that, if the focus for the edge with respect to the center be shortened by 1.5 mm, and if this shortening be gradually decreased until a medium zone is reached, the image would be as good as desired.

Owing to the difficulties and delays involved in sending the 15-inch objective to Allegheny, the corrector alone was taken there, particularly as Mr. McDowell was certain that he could introduce the required amount of aberration. Preparations were made for confirmatory tests by the Hartmann method in addition to Mr. McDowell's visual tests. The method of testing adopted, which followed as closely as possible the actual conditions under which the lens was to be used, consisted in forming a beam of parallel light by placing an artificial star at the principal focus of a 6-inch objective. A 4-inch objective of 60 inches focus placed in this beam formed an image of the star, and, if the corrector were inserted three inches from this objective, it would intercept a pencil of the same diameter and convergency and at the same distance from the focus as when used in its computed position at Ottawa. Moreover, tests by the Hartmann method or the ordinary knife-edge tests were equally easily applied.

A preliminary Foucault or knife-edge test with red monochromatic light, which was used in this test on account of the difficulty of obtaining monochromatic blue, showed that the edge focus of the system of 4-inch objective and corrector was about 0.7 mm shorter than the focus at the center. This is an indication, since presumably the 4-inch objective is free from aberration for light of this wave-length, that positive aberration to the extent of about 0.7 mm was present in the corrector. The chromatic difference of the 15-inch objective is about 2 mm, and hence this test showed that the corrector required an increased amount, previously estimated at about 1.5 mm, of positive aberration. A Hartmann test, using photographic light, showed the difference between center and edge to be about 0.2 mm. The difference between this and the visual test of 0.7 mm is almost exactly that due to the chromatic difference of the 4-inch objective.

Thus all the tests were in accord with one another and gave increased confidence in the reliability of each.

After a few minutes' figuring of the outer concave surface a visual test showed a difference between center and edge of about 4 mm, which was considerably too great. However, Mr. McDowell's skill in figuring enabled him at the second trial to get the surface so nearly right that repeated tests by different observers showed the difference from the required amount, 2.2 mm, to be indeterminable. A confirmatory Hartmann test showed the positive aberration present to be about 1.8 mm, 1.6 mm greater than before figuring.

The corrector was therefore considered completed, and the short time required to polish it, less than five minutes if the time spent in carrying it too far and bringing it back be deducted, is an indication that its failure to fulfil its computed purpose is probably due, as was stated above, to slight deviations of the actual from the computed figures unavoidable in practice. In this connection I wish to express my admiration of the skill of the John A. Brashear Co. in producing perfect optical surfaces, and my appreciation of the generous manner in which they have treated us in this as well as in all other matters.

Immediately upon my return from Allegheny, a Hartmann test was made of the performance of the refigured corrector. Using lantern plates and *Capella* as in the previous paper, the mean of a number of measures is given in Table I and shown graphically in curve *C*, Fig. 1. A comparison of curves *C* and *D* shows that the deviations from the mean focus are less with objective and corrector than with objective alone, although this advantage is probably counterbalanced by the greater astigmatism of the former system in the outer zone. If Hartmann's criterion "*T*" is computed for objective and corrector, as was done in the previous paper for objective alone with a value of 0.141, it is found to be 0.118, showing the system to be almost perfect so far as zonal aberration is concerned. The small deviation near the center is of no practical importance, owing to its relatively small area and to the narrow convergency of the pencils, and probably arises, as the visual curve shows, in the objective itself.

Determinations of the color-curve of objective and corrector for a median zone were made by Hartmann's method and the results are platted in Fig. 2. Curve *A* is for the corrector in its computed position

57 inches (144.8 cm) above the focus, curve *B* 59 inches (149.9 cm), and curve *C* 54 inches (137.2 cm) above the focus, while curve *D* is for the old corrector. These curves show that the point of minimum focus can be shifted to the red by lowering, and to the violet by

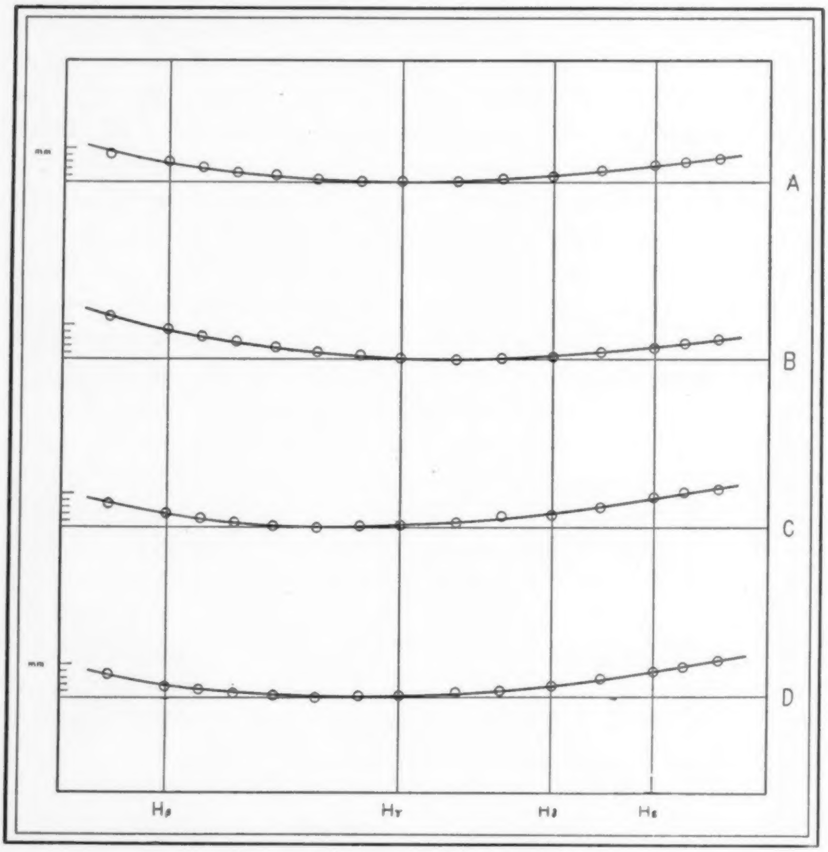


FIG. 2—Color curves of new corrector.

raising the correcting lens; this knowledge may be of value if, for any cause, the portion of spectrum under observation were changed. As is to be expected, the color-curves for new and old corrector do not differ appreciably in form.

It may be of interest to give some figures showing the exposures required to obtain measurable spectra with the new correcting lens.

In the three-prism plates, which have been confined to solar-type stars, the region measured lies between λ 4340 and λ 4580 and the exposure was sufficient to give good intensity over this range. In the single-prism plates the region measured lies between H_β and K, and the exposure was sufficient to allow K to be accurately measured and to sharpen up the diffuse H lines. I should estimate this exposure to be more than twice that required in a solar-type star of the same photographic magnitude around λ 4500. In single-prism work in order to render the spectrum more uniform in intensity the slit is placed about 2 mm below the minimum focus so that star light of wave-lengths about λ 4000 and λ 4800 is in focus on the slit. For this purpose the color-curves obtained above prove very useful.

TABLE II

THREE-PRISM SPECTROGRAPH

Linear dispersion 10.0 tenth-meters per mm at H_γ

Star	Phot. Mag. *Draper Cat.*	Slit-Width	Exposure
η Piscium...........	5.02	0.038 mm	70 mins.
ε Cygni.............	3.85	0.030	35 "

TABLE III

SINGLE-PRISM SPECTROGRAPH

Linear dispersion 30 tenth-meters per mm at H_γ

Star	Phot. Mag.	Slit-Width	Exposure
ι Orionis............	3.4	0.030 mm	10 mins.
o Andromedae........	3.9	0.030	25 "
ψ Orionis...........	4.6	0.035	40 "

As these figures show, the exposure times required, considering the size of the telescope, are short and compare favorably with those of any installation, although enough data have not yet been secured with the three-prism spectrograph to make accurate comparisons possible. If the magnitude of *η Piscium*, which is assigned as 5.02 in the *Draper Catalogue*, is reliable, then a star of the fifth photographic magnitude could be photographed in two hours with a slit 0.025 mm wide and a linear dispersion of 10 tenth-meters per millimeter, a very efficient performance for a 15-inch objective, especially

in the generally unfavorable conditions at Ottawa. Again, if the exposures given with the single-prism spectrograph be reduced by 50 per cent. or more, as would occur were the slit set at the focus for λ 4400 and the spectrum made measurable around this region, they would indicate similarly a very efficient condensing system. So far as the data at hand go, they indicate a decrease in the required exposure time with the new corrector of upward of 30 per cent. and if Table V[1] of the previous paper be reconstructed under these new conditions it would show the relative efficiency of the Ottawa installation to be equal if not superior to that of any other.

The successful issue of the attempt to improve the photographic image given by the Ottawa objective and corrector is of value, not only on account of the increase in the range and efficiency of the equipment, but also because of the greater freedom from chance of systematic displacement of the lines due to the more uniform illumination of the collimator insured by an image free from aberration. It is also of value as showing the possibility of obtaining a practically perfect corrector without sending the objective to the optician.

Another advantage, so far as this investigation is concerned, is the assurance of having a star image free from aberration as a starting-point for a trustworthy investigation into the actual effect of atmospheric disturbances on such an image. Some experiments were made, as recounted in the previous paper, on the effective diameter of the star image but, owing to the aberrations present in the old corrector, the results obtained gave only the combined effect of aberration and atmospheric tremor. Since the former has been removed, a repetition of the experiments should give an accurate knowledge of the effect of the latter. Newall has already given,[2] principally from theoretical considerations, a very valuable discussion of the effect of such an enlarged image on the design of spectrographs, and it seemed to me that a description of some experiments bearing on the same point

[1] Since the table referred to was published, Mr. V. M. Slipher has informed me that the exposure times assigned to the Lowell equipment were too large. They were taken from his paper on "Standard Velocity Stars," but Mr. Slipher states that the early plates were not only overexposed, but that the spectrum was made much wider than necessary. Under such conditions the Lowell equipment would make a much more favorable showing.

[2] *Monthly Notices*, **65**, 608, 1905.

together with the conclusions reached would also be of value. Newall considers the effective star image to be composed of a central "core," as he calls it, surrounded by a more diffuse "tremor-disk" and calculates on such an assumption the quantity of light transmitted by slits of different widths for different diameters of core and tremor-disk. I shall attempt to show how the percentage of light transmitted may be determined experimentally and obtain from that and other experiments some conception of the form and dimensions of the star image.

If one examines the visual star image in a telescope by an eyepiece of moderate power, it cannot escape notice that the image is not stationary, that it is displaced in all directions from its mean position, and moreover that the central diffraction disk is frequently expanded in a greater or less degree. These two phenomena, due entirely to atmospheric effects to which should be added the light in the bright rings surrounding the central disk, may be assigned as the cause for the enlargement over theoretical dimensions of the star image on a negative. The effects are all summed up in the resultant image, very much increasing its diameter over that due to the central disk alone.

As a test of this hypothesis stars of different magnitudes were photographed, a number of different exposures being given to each star. The diameter of the images varied from 0.050 mm equivalent to $1''.8$ for a faint star with short exposure to 0.130 mm or $4''.7$ for a bright star with medium exposure. A number of these images of moderate exposure had a central nucleus of about $2''$ diameter surrounded by an outlying penumbral portion some $3''$ or $4''$ in diameter. The diameter and intensity of this penumbra increased with increase of exposure, until in the longer exposures on bright stars its intensity became equal to the nucleus, resulting in the largely increased diameter noticed. Photographs of *Capella* on lantern-slide plates with exposures from 10 to 40 sec. gave images of diameters from 0.13 to 0.17 mm, or from $4''.5$ to $6''$, and these images differed from those of shorter exposure on fainter stars by being more sharply defined at the margins and of uniform intensity throughout. The minimum effective diameter of star images seems therefore to be in the neighborhood of $2''$, though this will evidently vary with the conditions of seeing. The diameter remains nearly the same for a considerable range of exposure and then begins to increase until it reaches about $6''$, although

part of this may be due to the spreading of the light in the film or to halation.

If the star be allowed to trail on the plate, the width of trail will give us a measure of the effective diameter of the image, and its appearance some idea of its character. The trails in every case, even in good seeing, were broken and jagged, showing the dancing of the image previously referred to. The enlargement or blurring is shown by the widths of the trails, which for a third-magnitude star on a lantern-slide plate ranged, even in the narrowest short parts, from 0.035 to 0.048 mm, or from 1″.25 to 1″.7, upward of twice the diameter of the central disk. For *Capella* the widths were from 0.050 to 0.065 mm, 1″.8 to 2″.3. If the microscope wires were set tangent to a longer strip of the trail, the above figures were increased about 30 per cent. For the old corrector the widths ranged from 0.070 to 0.110 mm, practically twice as great as with the refigured lens.

The widths of star spectra made under different conditions of exposure and focus were also measured and ranged from 0.048 to 0.110 mm. In order to prevent any widening due to drift in right ascension, the spectrograph was turned in position until the slit was parallel to an hour circle. As the focal lengths of collimator and camera are equal, the widths obtained give a measure of the effective diameter of the star image. The star used was *Vega*, which was chosen for two reasons: the shortness of exposure required insuring freedom from possibility of drift, and the type of spectrum rendering it certain that the full width was obtained. Similar experiments with solar-type stars showed that the discontinuous nature of the spectrum rendered it apparently much narrower.

It will be of interest here to give a table showing the increase of width with increase of exposure.

TABLE IV

Exposure	Width	Angular Diameter
5 secs	0.048 mm	1″.7
10 secs	0.049	1.7
15 secs	0.060	2.2
20 secs	0.075	2.7
30 secs	0.086	3.1
45 secs	0.095	3.5
90 secs	0.110	4.0

The above figures show how the outlying parts of the "tremor-disk," which has a "core" of about 1\."7 diameter, increase the width of the spectrum when the exposure is sufficiently prolonged to allow them to act on the plate.

With the old corrector the widths ranged from 0.085 to 0.115 mm, considerably wider than those given above.

The above experiments indicate that Newall's hypothesis in regard to the character and dimensions of the star image is in close argeement with the observed facts. The dimensions seem to point to a tremor-disk about 5″ diameter with a core 2″. If the proportions of the light transmitted by slits of different widths on which such an image is incident be computed, and if we obtain, exactly as was done in the previous paper, the proportional exposures required to obtain spectra of equal intensity over the same range of slit-width, a comparison of the two should show whether the assumption made is justified. In any case the experiments will show the actual loss at the slit, and this will be of value as indicating the direction in which improvement may be reached.

Three stars were used in this test *Vega*, *Capella*, and γ *Cygni*, and the spectra were made of the usual width, the greatest possible care being taken to insure uniform exposure over that width in order that they could be accurately compared. The exposures were so regulated as to obtain as nearly as possible equal intensity. Thus, neglecting plate factors which, within the limits of exposure time and intensity used, will not appreciably affect the result, a direct estimate of the percentage of light transmitted is obtained. The mean of a number of tests gives figures according to Table V; the seeing during these tests being slightly above the average.

In the following table the fourth column gives the observed times for equal intensities of spectrum while the fifth is the same with a correction for diffractional losses in the collimator with the narrower slit-widths. The sixth column is computed on the basis of Newall's hypothesis for a tremor-disk 5″ diameter with a core of 2″. The computed percentages are slightly higher than the observed, indicating that the actual image is probably somewhat larger than the dimensions chosen for the computed one. It must be remembered, however, that these figures are approximate only, the nature of the test not

TABLE V

SLIT-TRANSMISSION

Slit-Width			Comparative Times for Equal Intensity of Spectrum		
Div.	Linear	Angular	Observed	Eliminating Diffraction	Computed
1	0.025 mm	0″91	100	100	100
2	.050	1.82	40	50	54
3	.075	2.73	27	35	39
4	.100	3.64	25	32	34
5	.125	4.55	23	29	31
6	.150	5.45	23	29	31
8	.200	7.27	23	29	31

permitting determinations closer than 5 per cent. Moreover, a change in the steadiness of the air would change the observed figures very considerably, the effect of poorer seeing being to increase the diameter of the tremor-disk and core and consequently diminish the slit-transmission.

All the experiments on the diameter of images, widths of trails and spectra, and loss of light at the slit, indicate a form of star image which is of about the same dimensions and character as that supposed by Newall, and we may with confidence consider that the actual effective image of a star on the slit-plate is very much larger than has generally been supposed. Moreover, as the zonal tests have shown that the condensing system is free from aberration and the image almost perfect, the enlargement must be due to atmospheric disturbance of the wave-fronts and cannot be overcome by any optical system. It is evident, however, from the similar tests in the previous paper where less than 20 per cent. of the incident star light was transmitted by a 0.025 mm slit, that an optical system free from aberration is necessary for the most efficient performance. Even with such a system, however, only 30 per cent., or less, of the light collected by a 15-inch objective, can be transmitted by a 0.025 mm slit. This difficulty is much more serious with objectives of longer focus, as the image is probably enlarged proportionally. Indeed, Wright's tests[1] show that the Mills spectrograph makes use of only about 12 per cent. of the light collected by the 36-inch telescope, and

[1] *Publications of Lick Observatory*, 9, Part 3.

this in the unequaled atmospheric conditions of Mt. Hamilton. Part of the advantage of increase of aperture is thus lost by the consequent increase in the effective diameter of the image. The only means of diminishing this loss lies in using wider slits in our spectrographs. For example, a slit 0.05 mm wide with the 15-inch objective would transmit about 55 per cent. of the incident light, while a slit 0.075 mm wide, nearly 80 per cent. Unfortunately, wider slits mean diminished purity and loss of accuracy, although, as some experiments here have shown, the probable error of radial velocity determinations in stars of early types by no means increases proportionately with the increase of slit-width. These results also indicate the importance of using as large a collimator aperture as is consistent with homogeneous prisms, the consequent longer focus allowing increased slit-width with equal purity. The question of spectrograph design is, however, beyond the scope of the present paper, although I hope to publish shortly some experimental results bearing on this question.

I wish to express in conclusion my indebtedness to the Director, Dr. W. F. King, for his hearty and helpful co-operation in this work.

DOMINION OBSERVATORY, OTTAWA
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ON THE SPECTRUM OF CALCIUM

By JAMES BARNES

The study of the conditions which produce changes in the intensity and distribution of light in spectrum lines has direct application to astrophysical problems. In some former work[1] on the spectrum of magnesium the author found that a reduction of the pressure of the gas surrounding the arc influenced the intensity of many of the lines, when other conditions, such as the strength of the current, were kept constant. The intensity of the remarkable line λ 4481 produced in the arc in air or hydrogen at low pressures is constant for changes of current-strength from 0.5 to 7.5 amperes. Hartmann[2] showed that this line, produced in the same way but surrounded by air at atmospheric pressure, rapidly increases its intensity when the current is diminished through the above range.

Since calcium is a very important element in solar and stellar phenomena, and as a quantity of it can now be obtained in the metallic state at a reasonable price, easily turned into electrodes, and the arc made and remade even in air with small currents with much less difficulty than with magnesium, a continuation of the former observations, using calcium metal in place of magnesium, was an object of this report. At the same time the interesting papers of Humphreys[3] and of Konen and Hagenbach[4] on double reversals suggested an attempt be made to obtain the conditions which shall produce in a terrestrial source the double reversals of the H and K lines. These lines, I believe, generally appear doubly reversed in the spectrum of the sun's disk, which is usually explained by the existence of a luminous layer of calcium vapor in the chromosphere at a higher temperature than the layers above and below it. Finally it was expected that the arc between electrodes of pure metallic calcium burning in almost a vacuum would probably be the best condition for the appearance of new lines.

[1] *Astrophysical Journal*, **21**, 74, 1905.

[2] *Sitzungsberichte der K. Preuss. Akad. der Wissenschaften*, **12**, 1, 1903.

[3] *Astrophysical Journal*, **18**, 204, 1903. [4] *Ibid.*, **19**, 111, 1904.

The work was carried out with the following apparatus: A Rowland concave grating of six feet radius was used. Photographs were taken only in the first-order spectrum because the grating was very bright in this order, and also for the reason as pointed out by Humphreys, that it is possible to obtain false double reversals by the superposition of a sharp line of one order upon the reversal of another line of another order. Using the first order it is impossible for any of the ultra-violet lines of the second order to give such results in the case of any of the calcium lines considered.

The electrodes of metallic calcium were made about one cm in diameter and were mounted in an ordinary hand regulator for the work at atmospheric pressure. The time of exposure varied from half an hour to a fraction of a minute, depending on the strength of the current. During the long exposures necessitated by the small currents, the small number of times the arc required to be remade was very gratifying. When the arc is made a large number of times, as is required in the case of magnesium, conditions which approach those existing in the spark must certainly be produced.

For the observations at low pressures the electrodes were mounted in a large brass vessel of about 16,000 cc capacity, built specially for this purpose. It contained a long side tube closed by a quartz plate through which the radiation passed to the slit. There was also an air-tight arrangement for adjusting from without the distance between the electrodes. This vessel was exhausted by a Geryk pump and the pressure could easily be kept constant at one cm of mercury during the longest exposure.

The current was obtained from the college 110-volt circuit, and its strength varied by resistances consisting of incandescent lamps and iron rheostats.

CURRENT-STRENGTH AND PRESSURE EFFECTS

A systematic series of photographs of the arc in air at atmospheric pressure was taken. They show no remarkable changes in the intensities of the lines when the current is varied from 0.5 to 20 amperes. The first line to reverse is λ 4226.9, which occurs when the current-strength is only about one ampere. The K line reverses next and then the H line. These take place when the current is about 3

amperes. With heavier currents most of the lines are of course broadened and reversed. The lines $\lambda\lambda$ 4685.4 and 4355.4 were never obtained reversed. The two spark lines $\lambda\lambda$ 3737.1 and 3706.2, which are very strong in the spark spectrum, appear in the arc spectrum and are somewhat stronger when the current is small. They are however not increased in intensity when the arc is in a vacuum.

The variations which do occur in the intensities of the lines in the arcs of 0.5 and 20 amperes are generally toward an increase with decrease of current. Hale and Adams[1] attribute this to the temperature variation, but it seems from the following observations that the density of the surrounding vapor must play a rôle. With the arc in a vacuum plates were taken for current-strengths from 0.5 to 12 amperes. The only line that ever appeared reversed was λ 4226.9 and this only at the larger currents. At 12 amperes the H and K lines are no broader or brighter than at one ampere. Plate X, Fig. 1, shows how clearly these lines are defined in the arc of 12 amperes in a vacuum. The simplest explanation which will account for these observations is that the line λ 4226.9 is characteristic of calcium vapor when it is dense, while the H and K lines are characteristic of the rarer vapor. If this is the case the intensity of λ 4226.9 would be very large in the immediate vicinity of the metallic poles, the cooler and rarer enveloping vapor producing the reversal of this line and at the same time giving the H and K lines sharp and bright. The conditions are somewhat similar to those existing on the sun. There we have the H and K lines as the most prominent in the spectrum of the higher layers of the chromosphere, while that of the photosphere and chromosphere combined, as given by the sun's disc, contains λ 4226.9 as very strong.

The density hypothesis is not a new one. Sir William and Lady Huggins found that as they diminished the amount of calcium chloride added to a spark between platinum and iron electrodes, all the lines gradually disappeared leaving at last only the H and K lines. They account for their results as a density effect.

When, however, we consider such remarkable changes as occur in the intensity of the magnesium line λ 4481 with varying amounts of current, the explanation that it is due to temperature or density

[1] *Astrophysical Journal*, **25**, 75, 1907.

changes is hardly sufficient, and the suggestion first made by Liveing and Dewar, and developed by Hartmann and Crew, that the cause is electrical in nature, electro-luminescence, seems to have the most weight.

In calcium no lines were found to show such remarkable variations as this magnesium line. The two lines λλ 5189.0 and 4355.4, especially the first, appear to increase their intensity as the current is raised from 0.5 to 5.0 amperes. The line λ 5270.4 remains practically constant in intensity, while the line λ 5189.0 more than doubles its intensity for this range of current-strength.

NEW LINES

The new lines found by Saunders,[1] namely, the triplets beginning at λλ 3876.2 and 3754.2, which were obtained with an arc between copper poles moistened with calcium chloride, and which he says are faint and diffuse, appear very clearly and are quite sharp on the plates of the arc in a vacuum at 12 amperes. The triplet beginning at λ 3678.5 is somewhat diffuse on my plates. Arrangements are now being made to have the wave-lengths of these lines accurately measured by means of a comparison spectrum of iron.

The line λ 3653.6, which Kayser and Runge[2] give with the same intensity as λ 3706.2, does not appear on any of my plates.

It may be interesting to note that the only impurity in the calcium metal was a small trace of magnesium.

DOUBLE REVERSALS

In addition to the large number of plates taken with the arc in a vertical position, i. e., with the discharge perpendicular to the line joining the slit and the arc, others were taken with a right-angled arc. In some cases the positive pole pointed toward the slit, in other cases the negative. It was thought that if double reversals are possible in laboratory sources the right-angled arc with its positive pole facing the slit would be the best method for obtaining it. It somewhat fulfils the conditions existing on the sun, for around the positive pole we have a large mass of dense luminous vapor surrounded by rarer vapor driven off from the negative pole. It was hoped that the

[1] *Astrophysical Journal*, **21**, 195, 1905.

[2] *Abhandlungen der K. Preuss. Akad. der Wissenschaften*, 1891.

radiation from this rarer vapor, whether due to temperature or to electrical causes, would be large in intensity. Apparently it was not, for on a careful scrutiny of all the plates obtained with the vertical and right-angled arcs at atmospheric and lower pressures, with large and small currents, not a true double reversal was found.

The lines of the triplet λλ 4456.81, 4456.08, 4454.97 show multiple reversal, which is due to the superposition of the first line upon reversals of the last two. The doublet λλ 4435.86, 4435.15 gives a splendid illustration of a false double reversal, and is explained in the same way. These reversals are shown in Fig. 2. This is a print from an enlarged positive of the original negative and is therefore a negative; the light portions indicating the reversals.

The distribution of light in the lines produced by the right-angled arc with the positive pole facing the slit as shown in Fig. 3, *a*, is quite different from that produced when the poles are reversed as in Fig. 3, *b*. In the first instance (*a*) the reversals are narrow and sharp, while in the other (*b*) they are broad with very poorly defined edges. When such a difference exists, which depends merely on the orientation of the arc with regard to the slit, the other conditions, such as the current-strength and mean density of the vapor, remaining practically constant, any deductions as to the conditions which exist in sun-spots or faculae from observations upon variations in intensity of arc spectra obtained in the laboratory should include this observation.

An attempt was made to obtain a true double reversal with the calcium arc by the method used by Konen and Hagenbach,[1] when they obtained a multiple reversal of the line λ 2852.25 of magnesium. The method consisted in taking a plate of very short exposure of the arc when it is quickly remade after being extinguished, just as it was on the point of burning. The attempt was not successful.

It may be interesting to note that double reversals can be obtained by exposing the plate first to the arc under heavy currents and then to the same arc under a small current, the result being a composition of a reversal and a bright line. The result is the same as that obtained by Humphreys by placing a small quantity of metallic silver in the arc and exposing the plate long enough to get the effect of both the reversal and the sharp line when the vapor becomes rare.

[1] *Loc. cit.*

Thus, in conclusion, a true double reversal of any of the calcium lines in a laboratory source has not been found. The current-strength was never raised above 20 amperes, and the appearance of the lines with this current in no way indicates that double or multiple reversals would appear with heavier currents.

BRYN MAWR COLLEGE
January 1908

Minor Contributions and Notes

THE SPECTRA OF ALKALIES[1]

In his dissertation, *Contributions to the Knowledge of the Infra-red Emission Spectra of the Alkalies* (Jena, 1907), Mr. Arno Bergmann published his discovery of a new series in the infra-red portion of the spectra of potassium, rubidium, and caesium, so that in each of these spectra four series are now known. Between these recently discovered series and the first subordinate series there exists a relation similar to that between the principal and the second subordinate series. If we represent by E_1 and E_2 the oscillation frequencies of the termination for both lines of the pairs of the subordinate series, and by E the oscillation frequency at the termination of the new series, the differences $E_1 - E$ and $E_2 - E$ give very closely the oscillation frequency of the first pair of lines of the first subordinate series.

	Potassium	Rubidium	Caesium
End of the subordinate series as computed by W. Ritz* E_1	21,968.3	20,877.3	19,674.8
E_2	22,024.3	21,115.3	20,227.5
End of the new series as computed by A. Bergmann E	13,482.4	14,344.4	E' 16,791.9 E'' 16,887.7 E 16,839.8 Mean of E' and E''
Distance between the ends $E_1 - E$	8,485.9	6,532.9	2,835.0
$E_2 - E$	8,541.9	6,770.9	3,387.7
Oscillation frequencies of the pair of lines of greatest wave-length in the first subordinate series.......	8,502.0 8,563.1	6,489.3 6,743.1	2,642.3 3,193.5
	Observed by Bergmann		Not observed, but extrapolated from the series formulae of Ritz, computed by Bergmann

* *Annalen der Physik*, **12**, 295, 1903.

The series in the caesium spectrum consists of pairs of lines, and Mr. Bergmann states that in terms of oscillation frequency the two

[1] Translated from advance proofs communicated by the author.

lines of all pairs are equidistant. I should expect that they would draw together toward the end of the series similarly to the pairs of lines of the principal series. More exact investigations may show if this can be the case. The series of potassium and rubidium, also, probably consist of pairs of lines, as Mr. Bergmann remarks. They must be so much closer than the caesium pairs, however, corresponding with the smaller atomic weight of potassium and rubidium, that the dispersion employed hitherto doubtless could not separate them.

If it should be confirmed that the pairs of lines draw together toward the end of the series, I should further suspect that the first subordinate series is connected with the new series in the same manner as the principal series with the second subordinate series. Expressed in the form which W. Ritz has given to the series formulae we should then have:

$$\left.\begin{array}{l}\text{First subordinate series:}\\ \quad\text{Oscillation frequency}\end{array}\right\} = \left\{\begin{array}{l} f(2, a_1, \beta_1) - f(n, a, \beta) \\ f(2, a_2, \beta_2) - f(n, a, \beta) \end{array}\right\} n = 3, 4, 5, \ldots\ldots,$$

$$\left.\begin{array}{l}\text{New series: Oscillation}\\ \quad\text{frequency}\end{array}\right\} = \left\{\begin{array}{l} f(3, a, \beta) - f(n, a_1, \beta_1) \\ f(3, a, \beta) - f(n, a_2, \beta_2) \end{array}\right\} n = 3, 4, 5, \ldots\ldots,$$

where

$$f(n, a, \beta) = \frac{109675}{\left(n + a + \frac{\beta}{n^2}\right)^2}.$$

The new series would therefore give, for $n=2$, the oscillation frequency of the principal term of the first subordinate series, only with the negative sign, just as the second subordinate series, for the lowest value of n, gives the oscillation frequencies of the principal term of the principal series also with the negative sign.

In order to confirm these suppositions, we must wait to be sure for more accurate measures of the infra-red lines. The extrapolation of the formulae toward the side of the smaller values of n leaves so much leeway that we cannot state anything with certainty.

Nevertheless, this much is certain, that the new series bears a close relation to the first subordinate series, and that the four series in each of the observed spectra group themselves in pairs. There is a certain symmetry as in reflection, in the circumstance that the principal series ends at a higher oscillation frequency than the subordinate series, while the new series, on the contrary, ends at lower oscillation fre-

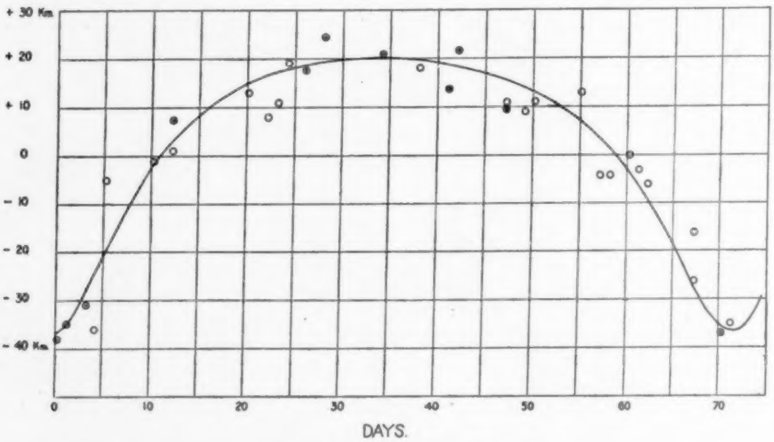
quency; and that the principal term for the one series-pair belongs to the principal series, for the other to the first subordinate series.

CARL RUNGE

GÖTTINGEN
December 1907

η VIRGINIS[1]

Forty-three measurable negatives of this star were obtained between February 22 and July 5, 1907. The first thirty-two negatives were made with the universal spectroscope as adapted for radial-velocity work, the dispersion at $H\gamma$ (λ 4340) being 18.6 tenth-meters per mm. Some five or six were made with the new three-prism spectrograph, whose linear dispersion at λ 4415 is 11.1 tenth-meters per mm. The



Velocity-curve of *η Virginis.*

balance were made with the new single-prism spectrograph whose linear dispersion at λ 4415 is about 32.4 tenth-meters per mm.

In September the last of the plates were measured and approximate values of the elements were obtained from the oscillation curve. Some of the larger residuals are probably due to the low dispersion, as it does not permit of the resolution of the spectral lines of the two components unless they differ in velocity by about 70 km per second. In cases where there was not this difference in velocity the center of intensity of the line would be shifted and an error would, consequently,

[1] Communicated by permission of the Chief Astronomer.

be introduced in the setting. Then, too, there were certain gaps in the curve and, taking all things into consideration, it was felt that more spectrograms would have to be secured before a rigid determination of the elements could be made.

The appearance of Naozo Ichinohe's article in the November number of the *Astrophysical Journal* and the marked similarity of the oscillation curve there given to that obtained here decided us to review the data already secured. Some of the plates where the velocities for the different lines were not in good agreement with one another were re-measured, and a new determination of the elements was made. These differed very slightly from the former determinations; the period of $71^{d}.9$ was accepted instead of my former value of $71^{d}.7$.

The following are the elements for the brighter component, which should be regarded as provisional only:

$P = 71.9$ days.
$e = 0.40$.
$\omega = 185°$ measured from ascending node.
Velocity of system $= +2.2$ km per sec.
$T =$ J. D. 2,417,643.50.
$a \sin i = 25,750,000$ km.

W. E. Harper

Dominion Astronomical Observatory
Ottawa, Canada
January 1908

SPECTROSCOPIC BINARIES UNDER OBSERVATION AT DIFFERENT INSTITUTIONS

With a view to assist in the avoidance of unnecessary duplication of observations of spectroscopic binaries, the following letter was recently addressed to the spectrographic observers at the principal observatories doing this kind of work. The replies are given in the order in which they were received. It would seem that these lists should be of service as observers are enlarging their programmes. This Journal will be glad to publish any additional data which observers may care to contribute at present or in future for the purpose.

Edwin B. Frost

YERKES OBSERVATORY, September 16, 1907

DEAR SIR: In the present state of research on the radial velocities of stars, so much remains to be done that it seems important to avoid duplication of work in certain directions, and to secure instead co-operation where feasible. Referring at present only to spectroscopic binaries, it is a matter of common experience that a large number of plates is often required before the period can be determined. This is likely to be wasteful of time, as the same phase may frequently be duplicated and needed phases may not be secured. Now it is decidedly unfortunate to have two different observers unwittingly enter upon the investigation of the spectroscopic orbit of the same star, while so many binaries remain almost untouched.[1] It has, for instance, lately come to my knowledge that an American observer, in starting upon radial velocity work, selected a spectroscopic binary for investigation which has been for a long time under observation by a European astronomer, who had nearly completed his determination of the orbit. The American had no means of knowing, however, that the investigation of that particular star had been undertaken in Europe. An unnecessary number of plates has thus accumulated, which could far better have been obtained for two different stars, as the orbit by either observer would doubtless be amply accurate for present needs.

The remedy that I would suggest is that observers beginning systematic observations of particular stars to get data for determining their spectroscopic orbits should in some manner communicate the fact to their fellow-workers in this field. The *Astrophysical Journal* might appropriately be made the medium for such inter-communications.

A second important advantage of this plan, if adopted, would doubtless soon be apparent. Observers who had casual spectrograms of a star stated to be under investigation by some other astronomer would doubtless be glad to communicate their results promptly, either by publication or privately, so that the investigation might be greatly expedited, the period determined much more accurately, and observations at important phases obtained which otherwise might not be utilized.

I would therefore inquire if you would care to communicate to the *Astrophysical Journal* a statement of the spectroscopic binaries now under investigation at your observatory or likely to be taken up within the next year. I shall of course be glad to make a statement of this sort for the Yerkes Observatory.

Very truly yours,

EDWIN B. FROST

HARVARD COLLEGE OBSERVATORY, September 21, 1907

The only spectroscopic binaries likely to be investigated at the Harvard College Observatory are those of Class A, in which both components are bright. They have been photographed here for many years, and the plates obtained will permit a very precise determination of their periods. No investigations of spectroscopic binaries of Class B, in which only one component is bright, are contemplated here at present.

EDWARD C. PICKERING

[1] It is probable that orbital investigations have been made for not over one-fifth of the spectroscopic binaries at present known.

MOUNT HAMILTON, September 23, 1907

The orbits of the following spectroscopic binary stars are under investigation at the Lick Observatory:

α Ursae Minoris (Polaris)	*SU Cygni*
δ Cephei	*U Aquilae*
X Sagittarii	*S Sagittae*
β Capricorni	*R Lyrae*
β Herculis	*l Carinae*
κ Pegasi	

It is not our purpose to undertake investigations of spectroscopic binary stars discovered at other observatories except in case of a variable star which may be necessary to round out researches that we have undertaken on other related variable stars.

W. W. CAMPBELL

DOMINION OBSERVATORY, OTTAWA, September 27, 1907

Binaries of which several plates have been measured:

ο Andromedae	*θ Aquilae*
η Virginis	*α Coronae Borealis*
η Boötis	*τ Tauri*
ι Orionis	*B.D.* – 1°1004
ψ Orionis	*ε Herculis* } Not many of these
ν Orionis	*δ Aquilae* } Not many of these
γ Geminorum	

A few plates only:

η Geminorum *d Boötis* *ο Leonis*

Proposed for the next year.

h Draconis *ε Ursae Minoris*

J. S. PLASKETT

POULKOVO, October 3, 1907

(Extract)

I am quite in accord with your suggestion that the spectroscopic binaries should be distributed among the different observatories; but I do not expect to be able to accomplish much in this direction under our climatic conditions. I might perhaps observe the brighter stars, not fainter than the fifth magnitude, such as:

δ Cephei	*δ Orionis*
ζ Geminorum	*ι Pegasi*
λ Tauri	*η Pegasi*
η Aquilae	etc.

We lack a suitable spectrograph, or rather a thermostat, for observing stars fainter than magnitude $4\frac{1}{2}$. In any case I shall be glad to take part in this work as far as possible.

I inclose a small list of our plates of such stars which have not yet been measured:

	Polaris	*α′ Geminorum*	*α″ Geminorum*	*ζ Ursae Majoris*	*δ Cephei*	*β Lyrae*
1900	36	..	..	..	..	..
1902	..	4	1	..	9	2
1903	..	26	2	..	13	19
1904	..	2	..	..	6	9
1905	16	11	6	16	2	10
1906	21	3	..	..	..	3
1907	..	3	8	..	..	..

From 1893 to 1907 (March) 2347 spectrograms have been obtained at Poulkovo, of which about 1200 have been measured and reduced, leaving 1100 which are not yet worked up.

A. BELOPOLSKY

POTSDAM, October 7, 1907

(Extract)

I am glad to communicate my list of stars. I have thoroughly worked up:

Polaris, β Persei, α Coronae, δ Orionis.

I have similarly followed a few other stars, but just now will refrain from making out a complete list, as I shall very soon refer to the matter more fully.

It would not be a misfortune at present, when spectrographic measurements are in the stage of development, to have the same piece of work carried out by several observers. We thus obtain a good check on the absolute correctness of the results.

J. HARTMANN

ROYAL OBSERVATORY, Cape of Good Hope, October 31, 1907

I heartily concur with your letter of September 17 as regards the undesirability of duplication of work in determining the orbits of spectroscopic binaries while so much remains to be done.

The study of these binaries has not hitherto formed part of our programme. I inclose, however, a list of stars of which we already have spectrograms and am quite willing that this should be published as you suggest. This list is subdivided under two headings, the first group containing those stars with spectra suitable for accurate line-of-sight determinations, the second those with lines too diffuse for exact measurement or in other ways unsuitable.

The list, which will also form the basis of our programme for the next year, has been prepared with a view to the determination of radial velocities, and more especially the epochs of observations have been selected so as to furnish as strong a determination as possible of the Solar Parallax.

For these purposes any information relating to the orbital velocities of such binaries as may be included in the list would be of the highest value to us, and in return for the same I should be happy to place at the disposal of other observers, in advance of publication, any information which I am able to furnish regarding special stars contained in the list for which I may receive application.

S. S. Hough

STARS OF WHICH SPECTROGRAMS HAVE BEEN ALREADY SECURED AT THE CAPE

BRIGHT STARS SUITABLE FOR VELOCITY DETERMINATIONS

α *Argus*	β *Geminorum*
ι *Argus*	γ *Geminorum*
α *Arietis*	β *Gruis*
α *Boötis*	α *Hydrae*
α *Canis Majoris*	α *Orionis*
δ *Canis Majoris*	α *Phoenicis*
α *Canis Minoris*	α *Scorpii*
α_2 *Centauri*	ϵ *Scorpii*
α_1 *Centauri*	α *Tauri*
γ *Crucis*	α *Trianguli Australis*

BRIGHT STARS UNSUITABLE FOR VELOCITY DETERMINATIONS

γ *Argus*	ϵ *Sagittarii*
δ *Capricorni*	δ *Scorpii*
β *Centauri*	θ *Scorpii*
α *Eridani*	λ *Scorpii*
β *Leonis*	α *Virginis*
ϵ *Orionis*	β *Argus*
α *Piscis Australis*	ϵ *Argus*

ALLEGHENY OBSERVATORY, December 16, 1907

(Extract)

I had not intended to let so long a time go by without complying with your circular request for our observing list of binaries. As you already know, I am heartily in favor of the proposal, and I look forward to seeing the programmes of other observers with much interest. I do not think it would much harm if several typical orbits were duplicated, however, and for this reason I intend to finish those stars that we have already well under way. In the case of other stars I will be glad to furnish velocities to other observers where they may be needed.

Our observing list includes (1) all the *Algol* variables that are within our reach:

β *Persei*	*U Ophiuchi*
λ *Tauri*	*U Sagittae*
R Canis Majoris	β *Lyrae*
δ *Librae*	

and as many more as experience may indicate that we can profitably attack; (2) binaries whose spectra are such that they may best be observed with low dispersion:

α *Andromedae*	ϵ *Herculis*
π *Andromedae*	δ *Aquilae*
ϵ *Ursae Majoris*	θ *Aquilae*
α *Virginis*	*6 Lacertae*
α *Coronae Borealis*	o *Andromedae*

Needless to say we shall add to this list from time to time.

FRANK SCHLESINGER

LOWELL OBSERVATORY, January 12, 1908

In response to your circular letter suggesting to radial-velocity observers a system of intercommunication which should advance the study of the orbits of spectroscopic binary stars and at the same time should avoid the present unnecessary duplication of observations, I am glad to submit the following list of such stars which we are observing here with a view to determining their orbits:

α *Librae*	λ *Scorpii*
β *Scorpii*	δ *Capricorni*
σ *Scorpii*	ϵ *Capricorni*

We had been observing also α *Andromedae* as opportunity afforded and have a fair series of plates,[1] but inasmuch as a provisional orbit has now been determined for this star—by Dr. Ludendorff, at Potsdam (*A. N.*, 4220)—we shall want to give the time to other stars. It is to be hoped all velocity observers will respond to your proposal in order that all may work more efficiently. To provide some system for the newly discovered star would it not be well for any observer wishing to undertake the orbit to communicate with the discoverer?

V. M. SLIPHER

YERKES OBSERVATORY, January 20, 1908

The list of spectroscopic binaries now under especial observation here is as follows. We should ordinarily include on our programme only such stars as were detected here.

13 Ceti	β *Lyrae*
δ *Ceti*	ϵ^1 *Lyrae*
ν *Eridani*	τ *Cygni*
9 Camelopardi	β *Equulei*
π^5 *Orionis*	ζ *Ursae Majoris, seq.*
μ *Orionis*	*Alcor*

The last five have recently been detected here.

EDWIN B. FROST

[1] The measures of those plates will be completed and made public in the near future only in case they are wished for use in investigating the orbit.

OBSERVATORY, CAMBRIDGE, February, 1908

Our work during the last two years has been more concentrated on solar work than on stellar observations. The four-prism stellar spectrograph is dismounted, and no new material suitable for exact determinations of velocity has been collected. Experiments are now being carried out with a grating spectrograph in photographing the red end of star spectra. I intend to carry these through before fitting the four-prism spectrograph with some form of temperature control.

Meanwhile, as for binaries, we have measurements of the following, for discussion:

α *Canis Majoris*	ζ *Herculis*
α *Canis Minoris*	α_1 and α_2 *Geminorum*

H. F. NEWALL

BONN, February 8, 1908

Extended series of observations of spectroscopic binaries for the purpose of accurate orbital determinations have been made here recently only of α *Aurigae* and ι *Pegasi*. The results of these investigations will be published presently.

Isolated spectrograms have been made here, however, of a large number of spectroscopic binaries. I cite the following, with the number of plates of each star:

α *Ursae Minoris*	5	χ *Draconis*	5
f Tauri	3	*31 Cygni*	4
μ *Ursae Majoris*	5	ε *Cygni*	6
η *Boötis*	6	ζ *Cygni*	4
β *Herculis*	5	ζ *Cephei*	4
ζ *Herculis*	5	η *Pegasi*	4
λ *Andromedae*	4		

These plates have been already measured and reduced. I hope to be able to publish the results in the not distant future, in connection with an extensive series of radial velocities which we have determined at Bonn during the last four years.

F. KÜSTNER

HARVARD COLLEGE OBSERVATORY, January 31, 1908

The compilation, by Professor Frost, of current observations of spectroscopic binaries suggests many important investigations, some of which are proposed below:

1. In the case of variable stars, especially those of short period, photometric observations should be made, as nearly as possible at the same time as the spectra are photographed. The Harvard Observatory is ready to undertake such observations if notified when the photographs are likely to be made.

2. There are several stars, like *S Monocerotis* and *Y Aquilae*, whose variability has been announced and confirmed, and whose designations have been

assigned to them as variables, but which show no variation at the present time, from careful measurements. (See *Harvard Annals*, **55**, 69.) It is possible that these may be *Algol*-stars of long period, or may have a period of almost exactly one or more days. Such a variation could not now readily be determined photometrically. These stars prove to be spectroscopic binaries, and photographs of their spectra, taken at any time, should show when the relative motion is zero, and when an eclipse or diminution in light is, therefore, probable.

3. The spectroscopic binaries *V Puppis* and μ^1 *Scorpii* have a range of motion of several hundred kilometers. Therefore, the exact form of their orbits should be determinable with a high degree of precision.

4. The star ζ *Ursae Majoris* (*Mizar*) is bright enough to be photographed with small instruments. A study of its variations with a slit-spectroscope would have great value. A large number of early photographs, taken at Harvard with an objective-prism, showed marked irregularities. No similar irregularities appeared in the photographs of β *Aurigae*, the only other star of this class then known. The investigation was abandoned owing to the difficulty when an objective-prism is used in distinguishing between a true doubling and that due to a change in focus of the principal telescope.

EDWARD C. PICKERING

POTSDAM, February 26, 1908

(*Extract*)

Professor Evershed and I are at present making extended series of observations with Spectrograph IV attached to the 32.5-cm refractor of the following spectroscopic binaries:

α *Andromedae*	β *Ursae Majoris*
β *Arietis*	ϵ *Ursae Majoris*
ϵ *Aurigae*	ω *Ursae Majoris*
γ *Geminorum*	δ *Aquilae*

With a few exceptions I have measured all the plates so far obtained of these stars. Elements of the orbit of β *Arietis* I have already published, and I shall probably soon be able to communicate preliminary elements for γ *Geminorum*. The series of observations of α *Andromedae* and ϵ *Ursae Majoris* presumably can soon be concluded. Although we have already obtained 60 plates of ϵ *Aurigae*, the star needs to be followed longer. This is also true of β *Ursae Majoris*, ω *Ursae Majoris*, and δ *Aquilae;* of the last two we so far have only a few plates.

H. LUDENDORFF